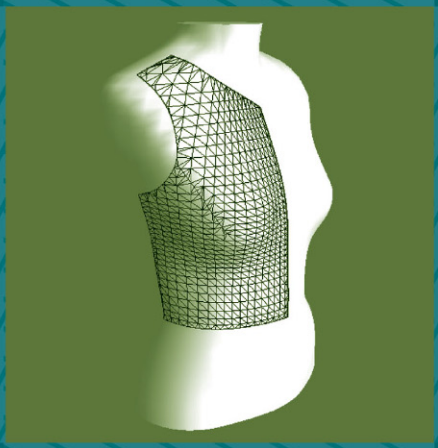
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Advances in apparel production

Edited by Catherine Fairhurst

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The Textile Institute

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Advances in apparel production

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Introduction

The main theme of this book is the design and production of apparel. Inevitably, most advances in these subjects depend upon computers and, more specifically, computer-aided design (CAD) systems, and so there is a concentration of the applications of these systems. Apparel production is not necessarily (in fact rarely is) in the same geographical area as the design, the financial control or the markets, therefore the CAD systems are needed as a powerful communication tool to assist speed and accuracy.

The book not only illustrates the complexity of the subject and the number of disciplines that have to be understood by the student and the practitioner in the apparel industry today, but also relies upon authors from different countries, which reflects the golbal spread of the industry. These authors have their own perspective and interpretation of advances in apparel production and it is important that students of the subject understand that there is no one right way within such a diverse and dynamic industry.

Some chapters are normative or descriptive whereas others, such as the chapter on CAD for yarn design, describe what are still research projects. Some topics may relate directly to each other, such as size charts in the Improving apparel sizing and fit chapter and the Computerised pattern making in garment production chapter, whereas others leave the reader to integrate the ideas according to their own interest and specialisms.

It is shown that, although there have been many significant advances and a deeper understanding of the production processes over the last 30 years, the major developments have been in the preparation for clothes production. The first chapter details the historical development of research into drape and shows that one of the major obstacles that has been encountered in developing three-dimensional (3D) CAD systems is the difficulty of modelling, measuring and predicting fabric drape in a garment. The representation of drape is of course important in scanning, mass customisation CAD-CAM, 3D design, simulation, 3D virtual prototyping and web-based shopping, and there is still further development needed in this area. This leads on into Chapter 2 with a discussion of computer-based colour matching and its

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importance to the designer and the whole supply chain. Colours in a designer's mind need to be quantified to be reproduced accurately, to communicate with the supplier and so to appeal to the consumer in today's environment of fast fashion demands. There have been problems standardising light cabinets and so the fundamentals of computerised colour matching are described together with advances of modern expert-based systems enabling objective colour standards produced in the form of a digital colour fingerprint which can easily be communicated electronically with a reduction in opportunities for misunderstandings.

Chapter 3, Computer-aided design for yarn, is an ongoing research project that is concerned with the development of fabric for CAD simulation using a study of the technologist/designer interface in developing yarns. There is consideration of how, in order to have a reliable apparel CAD tool, the simulation of the garment needs to be based on fabric simulation which consequently needs to be based on the correct yarn simulation. Chapters 4 and 5 relate to the importance of the fit of the completed garment and how sizing is a topic that has been able to take advantage of developments in technology. Dr Otieno in the chapter on sizing and fit considers the confusion in sizing systems and the importance of anthropometric data obtained from surveys. She outlines the historical origin of some sizing systems and continues the debate about what is good fit in relation to consumer satisfaction/dissatisfaction. She has found that there are variations in practice regarding sizing systems, size codes and ease allowances and so emphasises the importance of the development of accurate size charts based on empirical data. Professor Istook, in her section on body scanning, explains the inaccuracies of sizing systems, how difficult and impractical it is to take accurate measurements because the activity can be invasive and time consuming. She argues that even if the concept of fit is subjective depending on a person's perception of tight or loose it is still important that patterns are based on acccurate measurements. She describes the 3D body-scanning techniques that have been developed to overcome these problems, their advantages and disadvantages, and gives an overview of how these systems are being used in the industry and their future applications.

Chapter 6 on Computer-aided garment design using 3D body models contributes to the understanding of solutions for designing and illustrating garments on computer screens which enable designers to communicate their ideas to suppliers and buyers. This chapter describes a system developed by a research team for creating designs relative to an underlying 3D form using a mannequin or torso 'stand'. The system has been developed commercially for shoe design and can be used for other applications and specifically the example illustrated is a female flack jacket which can be designed to high specification.

The final chapter in the first section is an overview of the commercial advances in the development of CAD systems. This describes how computerised

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pattern making speeds up the product development process which is so important in the area of fast fashion and enables design and pattern construction to be integrated into a more continuous process.

The first part of this book has described research or applications relating to CAD systems that illustrate the recent advances in apparel design. It is, however, very difficult to separate the activities of design from production as many of the processes are integrated, as can be seen by the chapter on digital printing.

The second part of the book relates the advances in apparel production commencing with product development as the first stage of the cycle linking design with manufacturing and distribution. The Advances in apparel product development chapter reviews major models of new product development, concentrating on the concurrent product development approach and shows how CAD systems and product data management software tools can be used. Dr Tyler argues that in an era of fast fashion the product development process needs to be restructured with the role of the retailer being crucial to bring integration to internal systems and to the supply chain.

In the section on knitting technology, knitting construction mehods are described, including weft knitting technologies. Many of the advances in apparel production have taken place in the knitting production sector; here the shaping technologies that are available are discussed, including the 3D complete knitted garment production method.

The sewing machine still has the important function of joining woven and cut knitted fabrics. Garments are still mostly produced by cutting two-dimensional woven, sometimes knitted, pieces of fabric and seaming these together with a sewing machine. These machines have not changed radically. Chapter 10 describes the origin of the sewing machine, how peripheral the developments have been and how important it still is. Similarly, Chapter 12 describes the processes of pressing completed garments, where there has been little development in the technologies used to give his important finish; this is in contrast to the major developments in garment finishing to give different design effects to the garments.

The chapter on digital printing focuses on the technical and creative potential and limitations for working with digital textile print technologies; it shows how an understanding of the technologies can aid the creative process. The final chapter discusses a technique that has been developed to analyse the test results from the Kawabata Evaluation System and the software that analyses the results. This is of particular application to apparel production as it concentrates on the sewability of the material.

Advances in apparel production may be very rapid as the industry responds to consumer demand for fashion and these advances are being made particularly in the forms of communications where there are many opportunities for misunderstanding. However, in other areas, technologies are slow in developing; one reason for this may be that because of the fabric used manual handling on a sewing machine may be the most efficient and effective technique.

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Part I

Advances in apparel design

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1

Measuring and predicting fabric and garment drape

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1.1 Introduction

A critically important, in fact essential, property of a textile fabric and one which distinguishes it from other materials, such as paper or steel, is its ability to undergo large, recoverable draping deformation by buckling gracefully into rounded folds of single and double curvature.[1] It is this characteristic that plays a critical role in the fit, body conformation and wear comfort of garments and when translating three-dimensional (3D) body shapes into two-dimensional (2D) patterns and vice versa. According to the *Textile Terms and Definitions* of the Textile Institute,[2] drape is defined as 'the ability of a fabric to hang limply in graceful folds, e.g. the sinusoidal-type folds of a curtain or skirt'. It refers to the fabric shape as it hangs under its own weight; Cusick[3] defined the drape of a fabric as 'a deformation of the fabric produced by gravity when only part of the fabric is directly supported'. Drape, together with the effect of seams, determines the way in which a garment moulds itself to the shape of the body, this being a critical factor in comfort and aesthetic-related aspects of a garment and its fit. Ayada and Niwa[4] showed that the visual beauty and total quality of gathered skirts are closely related to the fabric mechanical properties of bending, shear and fabric weight and can be described by the parameters of formability, elastic potential and drape. Drape, in which the fabric shearing properties play a dominant role, is also a critically important parameter in the application of body scanning, mass customisation, computer-aided design and computer-aided manufacturing (CAD-CAM) and automatic pattern making to clothing design and manufacturing. The most significant developments in recent years have been the empirical prediction and modelling of drape as well as the move towards 3D design, simulation and virtual modelling (3D virtual prototyping) which enables the designer to 'drape and validate' their design onto a computer-generated manikin or one built off a body scan of a fit model, taking into account technical information, fabric type, colour, drape and stretch as well as the effect of seams.[5] Transforming 2D patterns into a 3D configuration

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that follows a body surface (and vice versa), of necessity, involves modelling the fabric physical properties[6,7] such as drape.

It is important to note that drape appearance depends not only on the way the fabric hangs in folds, but also upon the visual effects of light, shade and fabric lustre at the rounded folds of the fabric, as well as on the visual effects of folding on colour, design and surface decoration.[8] A fabric is said to have good draping qualities when it adjusts into folds or pleats under the action of gravity in a manner that is graceful and pleasing to the eye.[9] In practice, drape is usually assessed visually or subjectively and the actual assessment greatly depends upon often changing factors, such as fashion, personal preference, human perception. Bhatia and Phadke[10] discussed the influence of drape on clothing styles.

Drape is therefore a complex combination of fabric mechanical and optical properties and the seam properties, as well as of subjectively and objectively assessed properties. Furthermore, there is frequently an element of movement, for example the swirling movement of a skirt or dress, and therefore dynamic, as opposed to static, properties are also involved. As a result, in recent years, a distinction has been made between static and dynamic drape. This chapter deals with the measurement of drape and the empirical prediction and modelling of drape, but only briefly refers to drape models in CAD and Internet systems, these being dealt with in detail in Chapters 6 and 7.

1.2 Measurement of drape

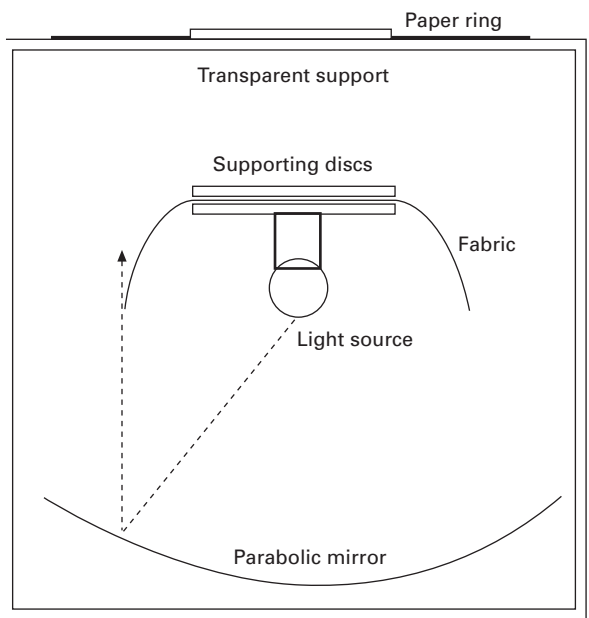
Fabric drape characteristics and behaviour are manifested in the appearance and fit of the garment and are usually assessed subjectively. Nevertheless, considerable research and development has been directed to the routine objective measurement and characterisation of drape and to relate drape, so measured, to objectively measured fabric mechanical properties, notably bending stiffness and shear stiffness. Chung[11] presented a detailed review of studies on drape, both static and dynamic, on both unseamed and seamed fabrics, and investigated the effect of seam allowance, type and position on woven fabric drape. She found that bending length increased with the insertion of a vertical seam, while drape coefficient increased with the addition of radial seams; increasing the seam allowance had little effect. The highest drape coefficient occurred with the circular seam located just out of the pedestal. Schenk *et al*.[5,12] developed a new method to measure the effect of seam stiffness on the stiffness of adjacent fabrics.

Early work concentrated on the development of instruments to measure bending stiffness because of its predominant effect on drape. Instruments (cantilever type) were designed to measure fabric bending length (the length of fabric that bends to a definite extent under its own weight), which provided a fairly good measure of the fabric draping properties, more particularly of

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the 2D drape, as opposed to the 3D drape that occurs in practice. It was soon realised, however, that, in addition to the major role of fabric stiffness, fabric shearing properties also play an essential role in determining fabric draping characteristics. Two-dimensional drape tests (cantilever method) are, therefore, unable to reflect fabric drape accurately, since the latter involves 3D double curvature deformations, which involve fabric shear. Therefore, to better quantify the fabric shear, various objective measurement techniques have been designed to include fabric shear and to simulate the subjective methods (e.g. laying the fabric over a pedestal or mannequin, allowing the fabric to fall naturally into folds and assessing the size and frequency of the folds). At present, the most widely adopted method is still to allow a circular disc of fabric to drape into folds around the edges of a smaller circular platform or template. Such instruments are commonly referred to as 'drapemeters'. Major developments are, however, taking place in the better quantification and understanding of the draped shape and dimensions produced by means of such drapemeters. These developments are discussed later in this section.

Pioneering work was carried out by Chu *et al*.[13] who developed a method of measuring drape by means of the F.R.L. Drapemeter, quantifying drape as a dimensionless drape coefficient (*DC%*). Cusick[3,14] subsequently developed what has become known as Cusick's drapemeter (Fig. 1.1) and which is still the standard and most common method of measuring drape. It has a parallel light source that causes the shape of the draped fabric to be projected onto a



1.1 Cusick's drapemeter. Source: Chung.[11]

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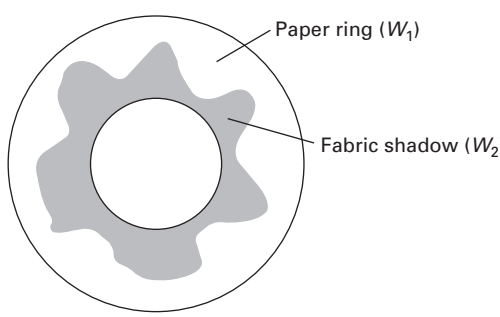
circular paper disc. The drape of a fabric is popularly defined as the area of the annular ring covered by the vertical projection of the draped fabric expressed as a percentage of the area of the flat annular ring of fabric, this being termed the 'drape coefficient'.[3] In practice, the contour of the shadow is often traced onto the paper and cut out for weighing.[15] Cusick[15] defined the drape coefficient (*DC%*) as the weight of the paper of the drape shadow (W_2) expressed as a percentage of the paper weight (W_1) of the area of the full annular ring (Fig. 1.2).

$$DC\% = W_2/W_1 \times 100 \qquad [1.1]$$

A measure of 100% on this instrument, which is widely used even today, indicates a completely rigid (stiff) fabric, while a value of 0% represents a completely limp fabric; the values in practice range from about 30% for a loose, open weave rayon fabric to about 90% for a starched cotton gingham, and about 95% for stiff nonwovens.[16] Since different template sizes can be used, which influence the drape coefficient, the diameter of the template must be given together with the drape result. Ideally, the template size should be such that the measured drape coefficient falls between 40 and 70%. Sudnik,[17] using an improved version of Cusick's drapemeter, published a table of drape coefficients (see Table 1.1), and also concluded that the optimum drape coefficient depends upon fashion and end-use. Some of the factors contributing to fabric drape are shown in Fig. 1.3.

Bhatia and Phadke[10] stated that since the draped sample will form pleats it will not remain in one plane and that the traced image is not necessarily the true projected one. They stated that understanding the drape mechanism requires a study of the following factors.[10]

- The drape geometry, i.e. the configuration of the draped sample, the drape measurement being employed to study the effects of fabric geometry.
- The drape diagrams, i.e. the projected 2D simplification of the 3D draped sample, which contains three significant items:
  - the area, which is the basis of the drape coefficient;



1.2 Drape image. Source: Chung.[11]

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Table 1.1 Drape coefficients (%)

End-use	Template A (24)	Template B (30)	Template C (36)
Lingerie	<80	<40	<20
Underwear	65–90	30–60	15–30
Dresswear	80–95	40–75	20–50
Suitings	90–95	65–80	35–60
Workwear, rainwear	>95	75–95	50–85
Industrial	>95	>95	>85

Source: Sudnik.[17]

– the number of nodes – formed as a result of material buckling, the phenomenon of buckling, the type of load applications and the boundary conditions;
– the shape of the nodes – when the nodes are uniform, the drape diagram is a cyclic function in polar co-ordinates. Converting these polar co-ordinates into rectangular co-ordinates simplifies the analysis between the shape factor and the drape coefficient.

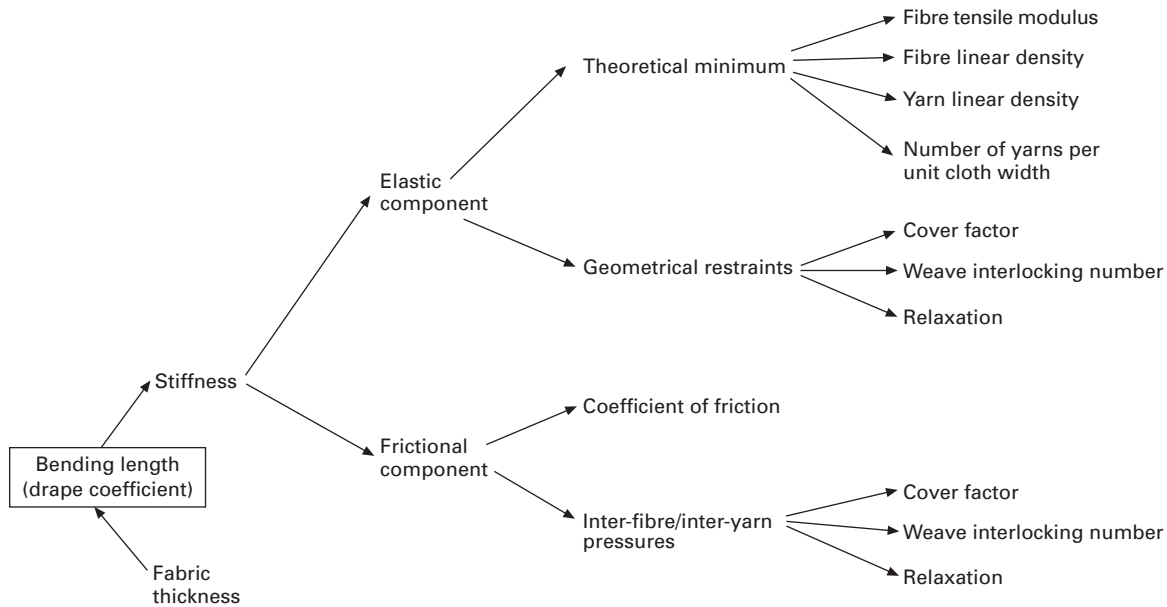
The drape geometry is predictable from the drape coefficient,[10] the number of nodes decreasing as the drape coefficient increases (inverse relationship).[10] Behera and Mishra[20] found a negative correlation between the number of nodes and fabric bending rigidity.

Typical examples of 'drapemeters' include those of Cusick, F.R.L. and I.T.F., and the M.I.T. Drape-O-Meter. Other principles of measuring drape include the force to pull a circular fabric sample at a constant speed through a ring, the force being termed the 'drape resistance' of the fabric. Collier[21] developed a digital drapemeter. Matsudaira *et al*.[22] used an image analysis system to measure static and dynamic drape. Vangheluwe and Kiekens[23] also used image analysis (video digital camera and computer-based image processing system) to measure the drape coefficient, while Stylios *et al*.[24] developed the next generation of drapemeters, enabling 3D static and dynamic drape to be measured by means of a charge-coupled device (CCD) camera as a vision sensor. Image analysis enables many measurements to be made in a relatively short time. The following are some of the standard test methods used to measure fabric drape:

- BS 8357;
- BS 5058/EN 9073;
- UNI 8279;
- AFNOR G07-109;
- ERT 90-1.

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1.3 Some factors contributing to fabric drape behaviour. Direction of arrows indicates whether an increase or decrease in a given parameter will produce an increase in the drape coefficient of the fabric. Source:[18,19]

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1.3 Empirical prediction of drape

1.3.1 Static drape

A number of experimental studies have been undertaken to identify those fabric properties that affect drape and to quantify such effects empirically, by means of regression equations and other analytical techniques. Peirce[25] carried out one of the earliest studies on fabric drape, early studies demonstrating the dominant role of fabric stiffness on drape, fabric weight playing a lesser role. Chu *et al.*[13] showed that drape depended upon three basic fabric properties, namely Young's modulus (Y), cross-sectional moment of inertia (I) and fabric weight (W) [drape coefficient = $f(B/W)$, where $B = YI$].

Later studies[3,15] demonstrated the effect of fabric shear and also shear hysteresis[21] on drape for both woven and knitted fabrics, 'shearing' being the deformation that results in a flat fabric when opposing forces act parallel to each other (shear stiffness being the shear angle at which a fabric begins to buckle). Xu and Wang[26] derived the following prediction equations for the shearing rigidities of worsted fabrics with short floats (e.g. plain, 2/1 twill, 1/2 twill and 2/2 twill):

$$G_1 = kn_2(0.4750S + 0.0151) \quad [1.2]$$

$$G_2 = kn_1(0.4676S + 0.0102) \quad [1.3]$$

where:

G_1 and G_2 are the warp and weft shear rigidities, respectively
n_1 and n_2 are the ends/cm and picks/cm, respectively
k is a constant depending upon the weave structure (= 1 for plain weave, $^2/_3$ for 1/2 and 2/1 twill, and $^1/_2$ for 2/2 twill)
S is the product of the warp and weft yarn diameters (in mm)

Cusick[3,14,15] demonstrated, both theoretically and experimentally, the effect of shear stiffness on drape. He derived the following empirical equation relating drape coefficient to bending length and shear angle:

$$DC = 35.6C - 3.61C^2 - 2.59A + 0.0461A^2 + 17.0 \quad [1.4]$$

where:

DC = drape coefficient
C = bending length measured with the Shirley Stiffness Tester and obtained as follows:

$$C = \tfrac{1}{4}(C_1 + C_2 + 2C_b)$$

where:

C_1 = bending length in the weft direction
C_2 = bending length in the warp direction

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C_b = bending length in the bias (45%) direction
A = shearing angle at a shearing stiffness value of 2 g wt cm/cm^2.

Tanabe *et al.*[27] used multiple-variance regression analysis to show that drape coefficient is affected by fabric bending modulus (B), bending hysteresis (HB) and weight (W), the correlation being increased by introducing the anisotropy of the bending properties into the regression equation.

Using the F.R.L. Drapemeter, Morooka and Niwa[28] derived the following empirical equation relating fabric drape to KES parameters, finding that fabric weight and bending modulus were the most important parameters.

$$DC = 5.1 + 115.0 \sqrt[3]{\frac{B_{90}}{W}} + 131.1 \sqrt[3]{\frac{B_0}{W}} + 1.2 \sqrt[3]{\frac{B_{45}}{W}} \qquad [1.5]$$

where:

W = fabric weight per unit area (mg/cm^2)
B_{90} = bending rigidity (g cm^2/cm) in the warp direction
B_0 = bending rigidity (g cm^2/cm) in the weft direction
B_{45} = bending rigidity (g cm^2/cm) in the bias direction
DC = drape coefficient

Using a theoretical approach, Hearle and Amirbayat[29] showed that a more complicated relationship existed between fabric drape coefficient and mechanical properties – possibly involving anisotropic in-plane and out-of-plane bending, cross-term elastic constants and nonlinearity of response. They related the fabric geometric form to two dimensionless energy groups J_1 and J_2, where, in terms of material properties:

$$J_1 = Y\ell^2/B \qquad \text{and} \qquad J_2 = W\ell^3/B \qquad [1.6]$$

where:

B = bending stiffness
W = fabric weight
Y = fabric membrane modulus
ℓ = the characteristic length defining the size of the material.

The more generalised expression is:

$$DC = f(J_1, J_2, \pi_3, \pi_4, \pi_5) \qquad [1.7]$$

where:

DC = drape coefficient
$\pi_3 = G/Y$
$\pi_4 = T/B$
$\pi_5 = \mu$

where G, T and μ, respectively, are the overall shear modulus, overall torsional rigidity and overall Poisson's ratio from all directions.

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Niwa and Seto[30] introduced bending and shear hysteresis into the relationship, relating drape coefficent to mechanical properties as follows:

$$DC = b_0 + b_1 \sqrt[3]{\frac{B}{W}} + b_2 \sqrt[3]{\frac{2HB}{W}} + b_3 \sqrt[3]{\frac{G}{W}} + b_4 \sqrt[3]{\frac{2HG}{W}} \qquad [1.8]$$

where:

DC = drape coefficient
b_0 to b_4 are constants
B = bending rigidity
$2HB$ = bending hysteresis
W = fabric weight per unit area
G = shear stiffness
$2HG$ = shear hysteresis

Hu and Chan[16] related the Cusick drapemeter drape coefficient to the KES-F mechanical properties, finding that logarithmic regression equations, of the form

$$DC = b_0 + \sum_{i=1}^{n} b_{\mathrm{i}} \ln x_i \qquad [1.9]$$

or

$$\ln DC = b_0 + \sum_{i=1}^{n} b_{\mathrm{i}} \ln x_i \qquad [1.10]$$

were better than simple linear regression equations, their results for bending and shearing were similar to other results, but two additional parameters, LT (tensile) and MMD (surface roughness) were also significant. They compared the various models and found that all bending and shear properties can be related to drape, but that three or four parameters were probably enough for an accurate prediction.

Matsudaira and Yang[31] found that there existed an inherent node number for any fabric, and the conventional static drape coefficient (D_{s}) could be measured accurately by an imaging system. Yang and Matsudaira[32] also derived regression equations from the static drape shape of isotropic and anisotropic fabrics, using cosine functions, and showed that static drape coefficient (D_{s}) and the number of nodes (n), can be calculated from the following equations:

$$D_s = \frac{4a^2 + 2b^2 + 2a_{\mathrm{m}}^2 + b_{\mathrm{m}}^2 - 4R_0^2}{12\,R_0^2} \qquad [1.11]$$

$$n = 12.797 - 269.9 \sqrt[3]{\frac{B}{W}} + 38\,060\,\frac{B}{W} - 2.67\,\frac{G}{W} + 13.03\,\sqrt{\frac{2HG}{W}} \qquad [1.12]$$

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where:

R_0 = radius of the circular supporting stand of the drapemeter (e.g. 63.5 mm)
a = constant showing the total size of a two-dimensionally projected area (mm)
b = constant showing the height of a sine wave of the two-dimensionally projected shape (mm)

a_m and b_m = constants showing fabric anisotropy, derived as follows:

$$a = 35.981 + 1519\sqrt[3]{\frac{B}{W}} - 204300\frac{B}{W} + 23.27\sqrt[3]{\frac{G}{W}} + 0.0178G$$

$$b = 29.834 - 1.945n - 0.0188G - 91.84\frac{2HG}{W}$$

$$a_m = 9063\left(\frac{B_2 - B_2}{W}\right)^{2/3} \quad \text{and} \quad b_m = 6224\left(\frac{B_1 - B_2}{W}\right)^{2/3}$$

where:

B = bending rigidity (mN m^2/m)
G = shear rigidity (N/m/rad)
$2HG$ = shear hysteresis at 0.0087 rad (N/m)
W = fabric weight (g/m^2)
B_1 = bending rigidity in warp direction
B_2 = bending rigidity in weft direction

Yang and Matsudaira[33] also quantitatively related the basic fabric mechanical parameters to static drape shape, using computer simulation.

Okur and Cihan[34] related drape to FAST properties, finding shear coefficient to have the greatest effect on drape, followed by the bending properties and the extension at 45° bias angle (used to calculate shear stiffness), 86% of the variation in drape coefficient could be explained by C2, Cl, EB5 and E20-2, only the first three being useful for the prediction of the drape coefficient. Behera and Mishra[20] found a negative correlation between fabric formability and drape coefficient.

Lai[35] used discriminant analysis to discriminate between four groups of fabrics (wool, silk, cotton and linen) with different characterised drape forms based on the Cusick drapemeter. Vaitkevičiene and Masteikate[36] developed a method of evaluating flared garment drapeability and investigated the influence of anisotropic fabric properties on drape. They presented a mathematical model for predicting the shape of horizontal projections of draped specimens, including those with seams.

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1.3.2 Dynamic drape

Elements of movement are frequently involved in garment drape, various workers having investigated dynamic, as opposed to static, drape. Yang and Matsudaira[37] derived the following dynamic drape coefficient (D_d), with swinging motion, which is more closely related to human motion in walking:

$$D_d = 90.217 + 0.1183W - 720.7\sqrt[3]{\frac{B}{W}} - 41.1\sqrt[3]{\frac{G}{W}} \quad [1.13]$$

Yang and Matsudaira[37–39] defined drape coefficients in the revolving state and also with a swinging motion and proposed a relationship between these coefficients and the basic Kawabata KES-F mechanical parameters. Subjective evaluation of dynamic drape is highly correlated with dynamic bending and shear properties as well as the KES-F hand values. Lai[40] applied the regression method and artificial neural network properties to predict the dynamic visual appearance of a swirling skirt from the fabric mechanical properties, with a view to replacing the subjective assessment with a more objective assessment. It was found[38] that the neural network method provided a more accurate prediction than the regression method. Two fabric mechanical properties were key in the prediction of skirt swirl, namely:

B = bending rigidity (gf cm^2/cm)
$2HG$ = hysteresis at 0.5° (gf cm)

Matsudaira *et al.*[22,41] showed that both the static and revolving dynamic degree of spreading of the (revolving fabric) drape coefficients decreased through the various finishing stages, especially with relaxation, defining the revolving drape increase coefficient.

Lai[40] applied the regression method and an artificial neural network to predict the dynamic visual appearance of a swirling skirt from the fabric mechanical properties, with a view to replacing the subjective assessment with a more objective assessment. It was found that the neural network method provided a more accurate prediction than the regression method.

1.4 Modelling fabric and garment drape

There is an increasing trend towards incorporating fabric mechanical properties, more particularly drape (or alternatively fabric bending and shear properties), into 3D garment systems. Hardaker and Fozzard[42] stated that one of the main obstacles in developing 3D garment CAD systems is the difficulty in modelling garment drape. Various researchers have attempted to model the draping behaviour of fabrics and garments, testing their models against experimental results. Generally, two approaches are followed in modelling garment drape, namely geometrical and physical.[43]

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The geometrical approach treats the fabric as a deformable object, represented by a grid or 2D array in 3D co-ordinates, and drape is simulated by approximating the shape of the fabric surface to constraint points.[44–46] Fabric properties need to be incorporated into geometrical models in order for them to be applicable to 3D CAD. The physical approach employs a conventional theory of mechanics, elasticity and/or deformation energy to model complex fabric deformation during draping. Conventional continuum mechanics and the finite element method[47–49] were used to simulate complex fabric draping with only limited success compared with the simple geometrical approach because the fabric undergoes complex and large deformations. For example, Collier *et al*.[50] used a geometric nonlinear finite element method to predict drape. They assumed the fabric to be a shell membrane with orthotropic rather than isotropic properties, finding that three independent parameters – tensile moduli in the two principal planar directions and Poisson's ratio – were required to predict drape. Gan *et al*.[51] applied geometric nonlinear finite elements, associated with a shell element, to model large fabric deformation, such as drape, the fabrics being considered as orthotropic and linearly elastic. Chen and Govindaraj[52] used a shear flexible shell theory to predict fabric drape, taking the fabric to be a continuous, orthotropic medium, and using finite element formulations to solve the governing equations numerically under specific boundary conditions. The fabric characteristics used in the model were Young's modulus in the warp and weft directions, shear modulus and Poisson's ratio. Their physically based modelling tied in closely with the processes of mathematical modelling and moved towards using drape modelling in apparel CAD and made-to-measure garment-making applications, also being applicable to the study of fabric deformation during the apparel assembly process.

Postle and Postle[53] developed a commercially applicable mathematical model for fabric buckling, with folding and drape, fabric bending and inter-fibre friction within the fabric being considered in their mathematical model, which involved solving nonlinear differential equations that had analytical (as opposed to numerical) solutions (called solitary wave or soliton solutions). Kang and Yu[54] developed a nonlinear finite element code to simulate the 3D drape shapes of woven fabrics, assuming the fabric was an elastic material with orthotropic anisotropy, also considering fabric drape to be a geometric nonlinear phenomenon. Stump and Fraser[1] applied a simplified model of fabric drape, based upon a 2D elastic ring theory, to the circular geometry of the drapemeter, using a parameter incorporating fabric properties and drape geometry, to characterise the drape response of the energy contained in a series of deformed rings. They could also explain the fact that a particular fabric does not always drape with the same number of nodes. They focused attention on the large deflection and nonlinear kinematics associated with deep drape.

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Bao *et al*.[55] conducted experimental and simulation studies on the MIT drape behaviour of fabrics, finding that the nonlinear finite element method, combined with the incremental method in which an elastic shell models the fabrics, simulated the large deformation of a fabric, such as in drape. They found that the fabric drape depended upon bending and torsional rigidity, but not on extensional or shearing rigidity.

Lo *et al*.[56] found that their model, using polar co-ordinates, for predicting fabric drape profile (characterised in terms of drape coefficient and node locations and numbers) could accurately predict the drape coefficient, node locations, node numbers and node shape in the fabric drape profile. Constants in the drape profile model could be obtained by regression analysis involving bending and shear hysteresis. They concluded that drape profile may be better predicted directly from bending and shear hysteresis.

Termonia[57] used a discrete model of fibres on a lattice to determine the importance of bonding pattern, laydown nonuniformities, fibre length and orientation distribution on the bending stiffness and drape of nonwovens. Another physical approach, involving the use of deformation energies with certain dynamic constants,[22,58–60] is particularly suitable for modelling dynamic garment drape in a virtual fashion, provided that effective collision direction and response algorithms are developed.

Particle-based physical models[61–63] have been proposed and show some potential. Based on the microstructure of woven fabric, Breen *et al*.[61] assumed that the fabric consists of a set of particles interacting according to certain physical laws. Stylios *et al*.[24] assumed the fabric is formed of rigid bar-deformable nodes and the governing differential equations of motion and deformation incorporating fabric mechanical properties were used to produce draping simulation. Fan *et al*.[43] stated that such conventional methods, based upon fabric mechanics, have the advantage of understanding the fundamentals but have difficulty in accounting for the effects of accessories, seams and styles, their application to more complex garments being questionable. Using a database of stored drape images of garments made of typical fabrics, Fan *et al*.[43] demonstrated the feasibility of using a fuzzy-neural network system to predict and display drape images of garments comprising different fabrics and styles. A prototype drape prediction system was developed to predict the drape of a ladies' dress style made from different fabrics. The advantage of the fuzzy-neural network approach is that it allows very fast computation, provided the database contains an adequate number of drape images, and used to train the fuzzy-neural model, the predicted drape image will be very close to the actual one. The disadvantage is that only a limited number of styles and changeable feature dimensions can be accommodated. Fan *et al*.[43] concluded that drape simulation was a complex and challenging task, and that their approach tested satisfactorily against ladies' dresses and for a wide range of fabrics.

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Cho *et al*.[64] developed a method of individual pattern making by modifying traditional systems so that they can be used in conjunction with modern 3D modelling techniques and which enables customised pattern making for individuals. They used a five-step drafting process: (1) defining the surface shape; (2) setting grainlines; (3) fitting the fabric to the surface shape; (4) cutting of the 3D surface; and (5) developing the 3D fitted fabric into a 2D pattern. They used 3D body data obtained by body scanning and their entire process involved the use of geometrical computer models. Doraiswamy *et al*.[65] developed an artificial neural network based model to predict fabric sensory properties including drape, from air-jet yarn properties.

Ji *et al*.[66] developed a practical mass-spring system to simulate the draping of woven and knitted fabrics, incorporating the fabric properties, measured on the Kawabata system, into the model to simulate dynamic draping behaviour. They[67,68] developed a method of 3D garment drape modelling, simulating the garment using a 3D quadrangular mesh based on the mass-spring system. The dynamic garment simulations can be implemented on a moving body. Zhong and Xu[6] used a separate wrapping procedure for 3D dressing simulation by introducing a force adaptation field to move all the particles on a pattern to form a 3D configuration that follows the mannequin surface. The 3D wrapped configuration provides a virtual garment for checking the fit of the designed patterns on a given mannequin and initial state for the draping simulation. Liu and Geng[69] reported on an expert system and 3D modelling technique for the intelligent design of 3D garments. They constructed a 3D garment prototype using the techniques of parametric cubic spline and bi-cubic surface patch. A series of production rules for the design of a 3D garment style was developed, and, using object-oriented technology, the knowledge base for 3D intelligent garment design was constructed.[69]

Niwa *et al*.[70] developed a method of objectively designing the optimum silhouette of ladies' garments based on fabric *mechanical* properties, such as tensile, shearing and bending properties. The optimum silhouette is objectively discriminated into three silhouette groups (tailored, anti-drape and drape), using a discriminant equation. Wang *et al*.[71] developed a digital engineering design system on the basis of particle-based models to simulate clothing dynamical behaviour. Zheng *et al*.[72] described a new shear tester, based on the trellis shear model, which appeared to be a more appropriate method of modelling actual shear deformation than other methods.

1.5 Drape models in computer-aided design and Internet systems

Drape modelling, in particular 3D visualisation of designed garments in draped form, is one of the key technologies in computer-aided garment design (CAD) and Internet apparel systems. It is essential for designers to

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assess the design, fabric suitability and the accuracy of garment patterns in a computer environment. It is also essential for the popular Internet systems to work effectively for trading and retailing as, without them, buyers and consumers will not be able to assess garment style, appearance, fit and suitability through the Internet. Chapters 6 and 7 of this book review various draping and other models in commercial apparel CAD and Internet systems, and therefore these are not discussed here.

1.6 Sources of further information and advice

Jacob and Subramaniam[73] and Hu and Chan[16] have briefly reviewed published work on drape. Subramaniam[74,75] undertook thorough reviews of the published work on fabric bending and drape and, in 1983, Subraminiam *et al*.[76] also reviewed published work on fabric shearing properties which play an important role in fabric drape. Bhatia and Phadke[10] reviewed the influence of drape properties on clothing styles. Chung[11] and Fan *et al*.[43] also reviewed the subject.

1.7 Concluding remarks

Initially, work on drape concentrated on its accurate measurement and on the empirical prediction of drape from the fabric mechanical properties, notably bending and shear rigidity and hysteresis. More recently, however, attention has increasingly focused on modelling garment drape, this being important for developing 3D garment CAD systems. Ideal drape models should not only be able to display the static drape of the garment realistically with 3D renderings of design features, colours and surface textures, but simulate the animated dynamic drape. It should have the capability to convert 3D shapes into 2D patterns or vice versa. Although most apparel CAD systems or drape models on the Internet are claimed to present realistic draping effects, the real performance needs to be evaluated by the end user.

Significant improvements in the drape models have occurred over the past two decades; however, further development in this area is still needed. As Wentzel[77] pointed out, 'the imagery of the virtual 3D sample is still flat; the stand and garment look somewhat sterile. Although fabric coefficients can be entered, the representation of the fabric drape still leaves some room for improvement.' When 3D animation is to be achieved, the challenge is greater. The resolution of the 3D virtual garment is still low in real-time presentation. Owing to the complexity and high polygon calculation, it takes a long time to achieve accurate performance of 3D animation. When the virtual garment is presented in a dynamic way or in 360° rotation, the figure tends to show a lot of shading and poor texture effects.

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2

Computer-aided colour matching of apparel fabric

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2.1 Introduction: principles and problems in maintaining colour integrity

Not too many years ago, a fashion-conscious consumer only had to worry about wearing the latest trends about four times a year. To be considered 'trendy', you simply had to fill your wardrobe in spring, summer, autumn and winter with the current season's garments, and sometimes the previous year's colours might even still fit the new season's trend for what was considered stylish. In today's world of fashion, an item of clothing is only considered to be 'in' if your envious friends are unable to obtain that same garment in the shops within one month of you purchasing it. While this fast and frequent turnover of retail garment stocks is clearly the fashion brand's answer to market demands, or a simple marketing strategy to increase sales, the established 12 fashion seasons per year have considerable consequences for the entire apparel supply chain.

Although computer-aided technology was available before personal computers became popular, many misunderstandings about the technology still exist throughout the apparel industry. Incomplete knowledge about its advantages, and conversely an understanding of the limitations of colorimetrics in general, and colour matching in particular, still restrict the benefits of this technology. When used properly by all members of the retail supply chain, towards a common aim, this technology must be seen not simply as a tool to tighten control on suppliers, but as a useful aid to help bring the designer's precise colour idea into the shops in the right season, satisfying the demands of the fashion-conscious consumer. This chapter describes the fundamentals of computer-aided colour matching in general, and, in particular, the advances of modern, expert-based technology, with its resulting benefits for the entire apparel supply chain.

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2.1.1 The importance of colour in apparel

There is no doubt that colour is a very distinctive product characteristic and probably the first aspect a buyer observes when scanning through clothes racks and shelves in the shops. But being attracted by colour and considering colour with regard to personal taste are two different things. So what is the phenomenon of colour? Why is it so important to fashion designers and houses that they are making bigger investments every year to ensure they are bringing the right colours to the market in every collection? In 1986, the *Wall Street Journal* (Alsop and Abrams, 1986) noted the importance and effect of colour in consumers' buying decisions: 'When designers at Berni Corporation changed the background hue on Barrelhead Sugar-Free Root Beer cans from blue to beige, people swore it tasted more like old-fashioned root beer served in frosty mugs. No matter that the beverage itself remained the same.'

There is obviously a psychological aspect to colour that has even aroused interest in its use in alternative methods of medication. The field of colour associations is also important, especially in the apparel world. Everyone knows that black garments makes you look slimmer, and the association of colours with natural objects has even created well-established names for colours. We are quite familiar with navy blue, charcoal grey or chocolate brown. Sometimes the associated colour has even disappeared in the term, but everyone has a good idea of a nice colour like cappuccino or plum. However, as has been noted, we only have *an idea*; and because every plum looks different or the colour of a cappuccino depends on who has made it, these are not true specifications of colours. Various problems, therefore, derive from the fact that colours are perceived as sensual stimuli. We cannot visualise precisely what someone else means by 'a friendlier yellow, with a hint of a scream', but we will all imagine the kind of colour described by this expression. Unfortunately for those who have to produce that colour idea, an imprecise characterisation of the colour will not result in the desired product, especially as more individuals become involved in the process. In addition, each viewer responds differently to the same colour stimulus as a result of age, experience, fatigue and defects in colour vision. Fortunately, alongside these individual and purely subjective ways of viewing colour, objective colour-assessment instruments are in place, facilitating the production of a specific collection of clothes that will trigger emotions – and hence the decision to buy. Of course, each individual consumer will describe his purchased item of clothing in his own words; most of the time he will be proud of his new pair of periwinkle trousers, but there will be days when he just cannot understand why he ever bought those ugly turquoise jeans.

2.1.2 Colour management in apparel supply chains

Today's many fashion-oriented industries have one thing in common: they

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are all facing the challenge of converting a designer's idea into a real garment. In this 'mind to market' process, various requirements must be fulfilled, of which colour is perhaps the most difficult to achieve. Style drawings, physical properties, care-handling instructions and choice of materials define a substantial percentage of the garment, but the colour the designer had in mind when he made his first sketches remains a fairly vague specification until it is defined as a 'colour by numbers'.

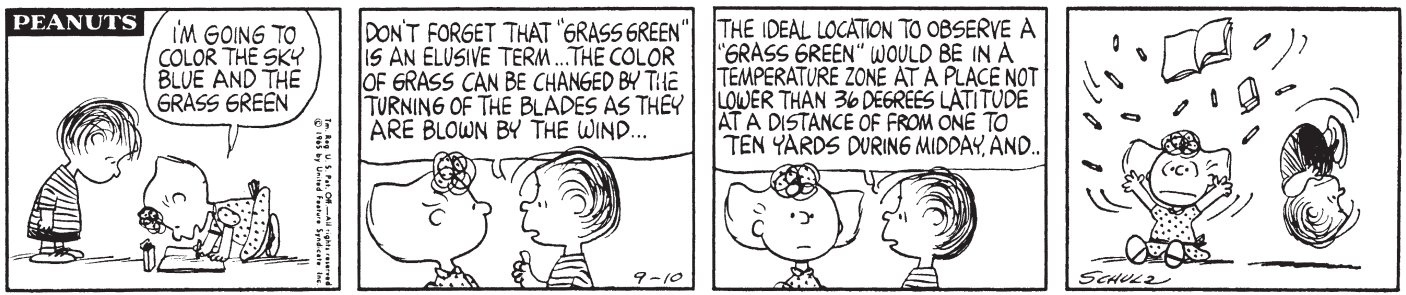
Colour is a subjective and emotional sensory phenomenon, and fashion designers are either inspired by forecasted trends or they simply try to get hold of their competitor's ideas. At this stage, the colour is still just an idea or a 'close to' sample that has to fit into the overall theme for the season, and in most cases, the colour's reproducibility on the material for the final garment has not yet been verified. This is the task of the technical, quality-oriented product development departments, which have to work with their sourcing partners to ensure that the designer's idea is created on a laboratory-scale sample for final verification. More than a year before the final product's launch to the market, it would be considered a success if the designer accepted this first attempt to convert his idea into real fabric. At this stage, a digital fingerprint of the initial colour idea can be created and used later for reproduction and colour inspection.

It is helpful for all members of the apparel supply chain if the colour idea is converted as early as possible into an objective and measurable target. This helps to improve communication about the colour and sets clear definitions for the suppliers, in the end allowing the whole process to be speeded up. The colour-matching part of the sourcing process, in particular, is more than happy to obtain a clearly defined target to match, by having customer and supplier speaking the same 'colour' language. The process of finding an appropriate combination of dyestuff, that also meets the garment's set criteria with regard to fastness and cost, can be lengthy. If the quality control departments of the fashion house or retailer could not respond clearly to the dyer, describing how the first lab-dip submission failed to meet the expected target, it would result in very lengthy, unproductive discussions on both sides as they tried to convert the demand for more 'freshness' into corrective actions to the colour recipe.

Thanks to the understanding that colorimetric tools only help – and do not limit – the designer's creativity, a growing number of spectrophotometers and relevant software systems are finding their way into colour-definition, feasibility-testing and colour-inspection processes. It took quite some time to convince the creative, garment-oriented sector of the supply chain of the benefits of colorimetric equipment. Their partners in dye houses and dyestuff manufacturers were among the first to implement colour measurement and computer-aided recipe prediction systems in their industries. The fact that colour is always a dispute between theory and practice is shown expressively in Fig. 2.1.

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2.1 Colour is always a conflict between theory and practice. © United Features Syndicate; reprinted by permission.

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2.2 Colour theory

Dealing with colour is of course a common requirement in the apparel industry, but there is a wide gap between a proper understanding of colour theory and the partial knowledge that is frequently seen, sometimes based only on knowledge passed on by word of mouth. A great deal of the management of the apparel supply chain is obviously related to 'talking about colour', but inappropriate and unusual usage of standardised colour theory could lead to misunderstandings and incorrect colour decisions within the supply chain.

A brief, 'real-life example' from my own customers will show how easily problems can arise about the understanding of colour theory. The quality manager of a fashion house had understood very well the need for standardised conditions when evaluating colour quality visually. In order to ensure a proper test for metamerism (metamerism occurs when two colour samples with different spectral power distributions appear to be the same colour when viewed side by side with one light source, but show a noticeable difference under another light source.), before the goods were shipped to the cut and sew department, he instructed his supplier to evaluate the finished fabrics under point-of-sale light and under standardised 'illuminant A'. The dye house manager decided to purchase a light cabinet, equipped with light sources according to his customer's specifications. When the first garments, made from supplier-approved production batches, arrived on the quality manager's desk, he inspected them under his office lighting with newly equipped 'CWF' and 'A' light sources. Unfortunately, he disagreed with his supplier's judgement and, wanting to locate the source of misinterpretation quickly, he decided to visit his supplier. When the quality manager went into the colour inspection room of the dye house, a glimpse at the supplier's brand new light cabinet was enough to convince him that he had located the source of the problem. 'I told you to use 'illuminant A' but your light cabinet shows that it uses 'F'. No wonder you can't see the metamerism I saw in my office because you are comparing the swatches under two fluorescent lamps.' The poor dye house manager requested the help of his light cabinet supplier and the problem was finally solved. The supplier was using a light cabinet equipped according to his customer's specifications. The light source, equivalent to the requested 'Standard illuminant A', had been established with tungsten filament lamps, known as light source F. The representation of point-of-sales light, often equivalent to 'Standard illuminant F11', had been created with TL84 light sources. The quality manager finally threw away his 'A' lamps, which were tungsten halogen lamps according to 'Standard illuminant A', and also the 'CWF' lamps. These are indeed often described as point-of-sales lighting, but are equivalent to 'Standard illuminant F2', whereas European point-of-sale lamps 'TL84' are equivalent to 'Standard illuminant F11'.

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Incorrect interpretation of standardised illumination and related light sources is probably one of the greatest sources of misunderstanding about colour theory and discrepancies between customers' and suppliers' visual evaluation of colour. Therefore the following definition of both by D. C. Rich (1998) may be useful:

> A light source is a physically realizable light you can switch on and off. Its spectral energy (power) distribution can be experimentally determined. To make a light source a standard source, the determination needs to get specified.
>
> An illuminant is light, defined by a relative power distribution that may or may not be physically realizable as a source.

In order to understand the importance of colour, it is essential to understand and always bear in mind the basic theory of this relatively subjective element. Colour is a visual expression that is created as the combination of three important elements.

Light

Without the presence of light, no one would care about colour because it is not noticeable in the absence of light. Think of the difficulty of distinguishing the colours of a forest on a dark night, or the mistakes you might make in your morning dressing routine if you didn't want to disturb your companion by switching on the wardrobe light to select a shirt and tie. Light is part of electromagnetic radiation and every light source consists of a certain distribution of spectral energy over a specific wavelength range. Only a very narrow range – between 400 and 700 nm – of the entire wavelength spectrum is visible to the human eye. Below 400 nm ultraviolet radiation is present and above 700 nm the near infra-red spectrum starts. The light sources we see every day emit a mixture of infinite monochromatic (single-coloured) lights at various wavelengths.

Depending on the different spectral energy distribution and its colour temperature, a light source can be described and represents a different visible colour of illumination. In light design, the various shades of – generally white – illumination play an important role in the interior design of shops. On the one hand the items look nice and attractive and on the other, it is important to achieve a close approximation to the conditions in which a specific garment will be worn. In order to compare colours visually at different locations, it is important for the objects to receive the same illumination. The CIE (Commission Internationale de l'Éclairage (International Commission on Illumination)) has, therefore, standardised various illuminants, the most common of which are shown in Table 2.1.

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Table 2.1 Standardised illuminants, typical light sources and common names

CIE illuminant	Light source	Colour temperature (K)	Common name
A	A Tungsten halogen	2856	Incandescent
A	F Tungsten filament	2800	Incandescent
C	Tungsten filament	6774	Daylight
D50	D50 (filtered)	5000	Daylight
D65	D65 (filtered)	6504	Artificial daylight
F11	TL84	4000	Shop light
NA	TL84/P15	4000	M&S TL84
F2	CWF	4000	Cool white, point of sale
F12	TL83	3000	TL83
F12	Ultralume	3000	U30

Object

In order to understand the miracle of colour appearance, we need to understand what is happening to the light falling on an object. Three main phenomena are recognised as the light interacts with an object. A certain part of the light is absorbed by the object and converted into heat. Depending on the object's optical properties, some light might be transmitted and a further part will be scattered. Parts of the scattered light are absorbed as well, and other parts can be reflected. It is the role of the dyestuff (as an object itself) to absorb a certain portion of the light radiation and reflect only the portion of the visible spectrum that represents the desired colour. For a green shirt, this means that certain amounts of blue, yellow and red energy are absorbed from a white light source, so that in the end only mainly green light is reflected and seen by our eye. The object's optical property to absorb light also has an influence on its apparent colour as there is a direct relation between the amount of absorbing object, i.e. dyestuff, and the amount of absorbed energy from the light.

Observer

As the receiver of the colour impression, the human eye is the most variable element when the appearance of colour is analysed theoretically. Two classes of receptors in the eye, known as cones and rods, are responsible for our ability to see and distinguish colour and light. The cones are the receptors for colour and are split into three different types of sensitivity to visible light at various wavelengths.

Although the human impression of colour is quite subjective, the combination of defined light and a light-absorbent object can create a reproducible reflection of light, and it is therefore up to standardisation to

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define the observer, allowing the establishment of systems that enable us to talk about colour. In 1931, the 2° observer and, in 1964, the 10° observer were standardised to represent the colour-matching results of the average human population with normal colour vision (ISO/CIE 10527). Both definitions were based on visual experiments to match a colour with the variable intensities of three different lamps. The 2° observer represents a sample of 1 cm diameter in a distance of 30 cm to the eye, whereas the 10° observer allows for a 5 cm diameter sample within the same distance, and is therefore most commonly used in the apparel industry (Fig. 2.2).

2.2.1 Colour coordinates

In order to be able to convert colour as a perception into colour by numbers, a vocabulary was created that allows us to describe colour as we see it. In addition to colour-classification systems that describe colours based on colour mixing, systems based on colour perception and colour matching are also in place. Colour-mixing systems are based on colour physics, whereas systems based on colour perception and colour matching take visual experimentation into account.

Based on the tri-stimulus values (the mathematical product of the CIE illuminant, reflection and CIE observer) of the CIE system, several attempts were made to try and establish systems using representative numbers or



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coordinates, correlating to the visual perception of colour. The CIE L*, a*, b* system, standardised in 1976 and still widely used, comprises three rectangular coordinates, representing lightness (L*), redness (a*) or its opposite greenness (–a*), and yellowness (b*) or, respectively, blueness (–b*). In addition to the rectangular coordinates, the characteristics of a colour can also be described by its hue (h) and its chroma (C*).

It follows that given the colour coordinates of two objects, their differences can be calculated and described. Not only does the CIE L*, a*, b* system allow the comparison of coloured objects with regard to being lighter, darker, more or less reddish (greenness) or bluish (yellowness), but a total colour difference (dE*) was also used to establish a general acceptance of colour difference.

2.2.2 Colour tolerances

As soon as a numerical system was introduced to describe and compare colours, it was also used to make decisions about colour quality. Visually noticeable colour differences should then be reflected in numerical values to allow the detection of colour differences in general, facilitating both perceptibility and decision-taking if the difference falls within the tolerances of acceptability. In order to provide such quality metrics, optimised equations were established with better comparability for visual decisions. Among today's most commonly used colour difference equations are the CMC (l:c), CIE 94, CIE de2000 and DIN99 formulae. In addition, some non-standardised tolerance formulaes, such as the M&S 89 or Datacolor, are widely accepted in various areas of the colour-related industries.

Irrespective of which colour difference equation and tolerance formula is used, the apparel supply chain needs to observe three main principles to ensure successful use of colorimetric colour assessment:

- Define and agree on the most suitable colour difference equation for the application.
- Define and use the same illuminant/observer settings for the colour coordinate calculations, as 'colours by numbers' are still dependent on these variables.
- Define and agree on a useful and achievable tolerance factor, taking into account the instrumentation used, the colour uniformity of the fabric and the visually noticeable tolerance.

2.3 Colour-measurement technology

There is more similarity than might appear at first sight between a human being receiving a specific visual colour perception and a modern colour

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measurement device. Both 'colour measurement systems' consist of the three components described earlier that are needed to create a colour perception. Despite these similarities, modern spectrophotometer-based technology has several major advantages over the human instrument. Since a spectrophotometer observes only the object itself and is not disturbed by any surrounding colour (at least it should not be if the sample preparation is properly done), it eliminates the distraction that even an experienced colourist has to face. In addition, the illuminating light source in a spectrophotometer is generally less relevant because the instrument uses only the difference between available illumination and detected percentage reflection, returned from the object. The aspect which has a major impact on both methods is the illumination and the observing angle, related to the vertical axis of the object. Depending on their method of determining the colour stimulus, there are two main categories of instruments: colorimeters and spectrophotometers. Colorimeters measure the CIE tri-stimulus values as quantities, whereas spectrophotometers calculate the colorimetric quantities from spectral data, in variable wavelength ranges and with different bandwidths. The location of the illuminating source and position of the observing optics directing reflected light to a detector have resulted in the commonly used geometries shown in Table 2.2.

The different geometries have different advantages and disadvantages and are therefore preferred by different industries and for different applications. While the 45°/0° or 0°/45° directed geometries can correlate to visual perception on glossy materials where the observer tries to exclude surface gloss by placing the object at a specific viewing angle, the diffuse illumination of d/8° geometries in specular-included mode allow for complete non-observation of specular reflection and texture. This is exactly what is desired when the application is colour matching, as the entire colour appearance is needed, regardless of its surface or texture, to serve as the standard to match. Irrespective of which geometry is finally chosen for instrumental colour assessment, it is important that all colour communicating partners agree on one common

Table 2.2 Common measurement geometries

Geometry abbreviation	Illuminating angle	Viewing angle	Comment
d/0°	Diffuse (sphere)	Perpendicular	Standard in paper industry
45°/0°	45° from the normal	Perpendicular	Direction sensitive
0°/45°	Perpendicular	45° from the normal	Direction sensitive
45°/0°:c	45° circumferentially	Perpendicular	Not direction sensitive
d/8°	Diffuse (sphere)	8° from the normal	Allows for in- and exclusion of specular component

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geometry and are aware of the specification limitations of the individual instruments.

For modern apparel supply chains, it has become an essential part of their sourcing processes that they are using precise and accurate instruments to evaluate colorimetric values, and so the comparability of instruments' results (inter-instrument agreement) has reached an importance that was not considered some years ago. When considering instrumental colour measurement today, the most important aspect is to observe all of the instruments' performance and ability to maintain specifications. Mathematical correlation techniques are also used to try and tighten the agreement between different instruments. However, noticing when an instrument is starting to diverge from its specifications is much more important than trying to bring an off-tolerance instrument back to a standard by using a correlation or profiling technique, which would in any case represent a major modification from its original performance (Fig. 2.3).

2.4 Colour-matching technology

Colour matching in apparel is often directly related to colouring textiles with certain amounts of dyestuffs in order to achieve the designer's idea of colour



2.3 Datacolor 650™ benchtop spectrophotometer.

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for the final garment. As today's supply chains become more global and consumers more critical with regard to colour quality, so the colour matching of all the components for a garment becomes more important. This is especially so today, bearing in mind that it is not only the zip and buttons that are made of different material from the fabric, but it is also common that the collars, sleeves and main material are sourced in different locations in the world. It is important, therefore, to ensure that when the materials reach the cut and sew department, they all match a defined standard at an early stage in the sourcing process.

Colour matching is much more than selecting the dyestuffs or pigments which, in the appropriate combination and concentration, should result in the desired colour of the final material and meet requirements with regard to fastness, cost and quality. As part of the process of converting a designer's concept or idea into a product, colour matching is perceived differently by supplier and designer. For the designer, his idea is something new, unique and special, born of inspiration and aiming to win the appreciation of the end-user. For the people within the supply chain who have to ensure that the colour idea finds its way onto the fabric, the designer's colour idea is 'just another reproduction' of what has already been done several times before. They might see a potential for lower production costs when they try to match a colour with new components or simply use an archive of historically accepted matches to run searches and make minor adaptations to an original recipe. Before the scientific analysis of colour theory and the understanding of colorimetry, the skill set of knowing which colorants or dyestuffs to mix and in what proportion to obtain a specific result was purely experience-based and required a long learning curve.

So-called colour models have to be created to understand the interaction of various percentages of dyestuffs as input, and their resulting colour as output. In general, the application of a specific colour to a raw material follows the principles of subtractive mixing, according to which – for simplicity here – we can say that red, yellow and blue can create every colour, up to black.

As explained in Section 2.2, dyestuffs have the ability to absorb portions of the visible spectrum from a so-called white light that reaches a material and is reflected with the resulting spectrum, after subtracting the portion that was absorbed. The three theoretical subtractive primaries relevant to describing the colour matching process in the apparel industry are cyan, magenta and yellow. Table 2.3 shows the ability of these primaries (relating in practice to dyestuffs) to absorb separate portions of the visible spectrum and their resulting, perceived colour.

Since simple red, yellow and blue dyestuffs do not really represent the spectral reflectance of these three theoretical subtractive primaries, additional dyes are required in order to build up an appropriate colour range. There are

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Table 2.3 Theoretical subtractive primaries and their ability to absorb light

Theoretical primary	Subtracted light	Resulting colour
Cyan	Red	Cyan
Magenta	Green	Magenta
Yellow	Blue	Yellow
Cyan and yellow	Red and blue	Green
Magenta and yellow	Green and blue	Red
Cyan and magenta	Red and green	Blue
Cyan and magenta and yellow	Red and green and blue	Black

various colour mixing laws which all have in common the fact that they define the relationship between the colour components and the spectral data in a linear way, with the prerequisites of scalability and additivity of that relationship. When analysing increasing concentrations in a dye bath and the effect of the resulting/transmitted amount of light, we refer to creating a concentration series or colour ramp. Bouguer detected in 1729 that a doubling of a defined thickness of a transparent material like coloured glass results in an exponential effect of transmittance through the glass. The logarithmic transformation of this transmission is known as absorption and it fulfils the scalability requirement whereas transmission does not. This law was rediscovered by Lambert in 1760, and then approximately 100 years later, Beer proved that the discoveries of Bouguer and Lambert about absorption and material thickness were also valid for liquids of varying concentration. It is important to recognise that this simple subtractive mixing law should only be used within concentration levels where the spectral data are scalable, and thus computer-aided colour matching, as explained later, is limited to the linear level of concentrations.

Despite taking into account all the background theory, it happens quite often that a visually acceptable match, found after lengthy trials and using dyestuffs that seem to fulfil fastness and other fabric property requirements, unfortunately turns out to be too difficult for a controlled production process in the dye house; and so the time-consuming efforts have to start again. Fortunately, computer-based colour matching systems that are part of an integrated process and recipe management system do help a great deal to achieve the right colour recipe in the shortest possible time, while also considering various other aspects, e.g. producibility, cost and environmental demands.

In far-distant history, the dyer's job must have been much simpler, at least – but probably only – with regard to the coloration process. When natural indigo, purple or saffron were among the most popular dyestuffs, it was simply cost that dictated the amount of dyestuff used. It was – and still is – the human desire to be individual and distinguished from one another that

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created what we today call fashion. At the time when the sources of these natural dyestuffs were quite limited or very expensive to use, individual colour was a sign of wealth and an ability to pay for individuality. The invention of artificial dyestuffs – e.g. synthetic indigo by BASF in Germany about 110 years ago, driven by huge demand for blue dyestuff for navy and general military garments, and of course blue workers' overalls – was one of the influences that allowed colour (and loads of colour) to become a fashion consideration. While it took 100 kg of Indigofera-bush leaves to produce 2 kg of dye from its natural source, synthesis allowed much larger amounts of dyestuff to be produced much faster. Whereas in the nineteenth century, the range of available dyestuffs dictated colour inspiration, the flower-power age of the 1970s brought designers' colour ideas to the desks of colourists and dyers that quite often could not be produced on textiles. Cross-industry inspiration from paints, inks and plastics required a fast and steady enlargement of the dyestuff range, and still today scientists in dye manufacturers' laboratories are trying to build bigger colour ranges for the various different fabrics and materials, in order to allow dyers to create a more colourful world of clothing.

2.5 Colour communication and approval

In every industry, the chicken-and-egg question can be asked: whether new technology has empowered the creative side to broaden its creativity, or whether new fashion trends and consumer's demands have requested and forced new technological developments. The apparel industry is an obvious example in which technological progress works hand in hand with inspiration or design. To fulfil the concept of 'fast fashion', the entire sourcing process has been adapted.

The colour matching step of the whole product development process received less attention in the past than it does today. It was quite normal procedure for all the creative processes and development of colour palettes, physical storyboards and final merchandise on offer to be seen purely through the eyes of the fashion house or retailer. Their feeling of responsibility ended with the definition of the season's colours for garments. Finding the appropriate recipes to fulfil the fabric's visual, commercial and physical objectives fell on the shoulders of the dye manufacturers and purchasing departments, and quite often limited the dyer's ability to meet set targets in a timely and economically attractive way. The 'exodus' of European and North American dye houses to countries with less strict ecological and labour limitations still continues today. Quite often, cost-driven sourcing met immature technology in the colour creation area. Computer-based colour matching and even the use of spectrophotometers were quite unusual at the beginning of that source-shifting phase. It is not surprising that fashion houses and big retailers, who

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had never had to become familiar with the numerical specification of colour, remained unconcerned about the existence of any colorimetry equipment at their suppliers.

Before major technological advances were established in apparel supply chains, the colour target was simply defined as a verbal expression, or in better cases as a representative colour swatch, either from a colour atlas or from some kind of material that had inspired the designer. When the supplier has received his colour target, he tries to obtain a result on the defined fabric in his laboratory environment and is already determining what will have to be considered to obtain the same result on the scale of a potential production run. Quite some time will pass by and money will be spent on courier services sending physical swatches between the supplier and approving department at the retailer's or fashion house. Production can start once the result is approved, and everybody has to hope that the initial supplier of the approved lab-dip sample also remains the supplier for the bulk production. If a second supplier needs to be found in the instance of production bottlenecks or larger demands for fabric than initially estimated, it is very likely that he will have to do the recipe evaluation – already done by his competitors – all over again. It is mainly a question of luck as to whether the same recipe will be used, since the second supplier also has the same difficulty of an undefined target and might make a different choice of dyestuffs, with the result that the phenomenon of metameric garments is somehow already pre-programmed.

2.6 Technological advances in matching colours

The colourist faces multiple challenges to perform excellently in the various types of colour matching. From 'simply' creating samples of new colours based on a designer's description of his inspiration, to the reproduction of a duplicate batch from a given recipe, there are also tasks such as recreating previously generated colours using different ingredients, or producing a matching colour on a different material from the original standard. The first task is already difficult, but considering the variables and deliverables of the other three challenges, it is probably the job requiring the least experience. To create a spectral or invariant match, the material and selection of dyestuffs is fixed, as explained in Section 2.2. Colourists are most often charged with creating conditional or metameric matches, the third of the above tasks, when cost, environmental or production limitations, or simple availability require a substitution of one or several dyestuffs in a previously accepted recipe. It is highly likely that the batch made using the resulting recipe will be – as the name suggests – metameric. Unfortunately, the acceptance of such results is still quite low, but an understanding of the source of the partial mismatch on both sides of the sourcing process would help to avoid lengthy discussions and costly requests for repeats in the colour approval

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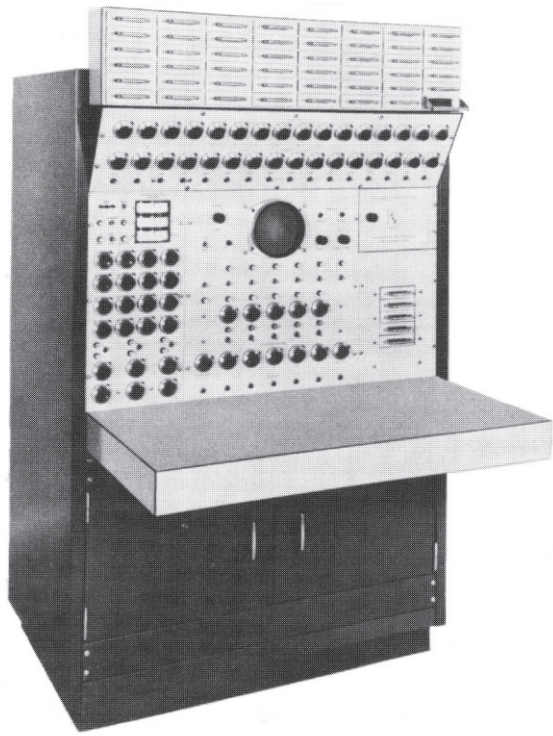
process. Another quite common request for dyes in apparel supply chains is to match the colour of a standard that was supplied on a different kind of material from the final fabric chosen. In such cases, the colourist has to drive his selection of dyestuffs towards the final textile substrate, but he must also consider the technological properties that the fabric has to fulfil. The major challenge in the matching and also the approval process for this kind of task is to understand the influences of the different surface characteristics. Gloss and texture strongly influence the appearance of colour, so that although an almost invariant match might be achieved with regard to the spectral characteristics of standard and batch, the influence of the surface can result in endless arguments between supplier and customer.

The technological advances in the apparel-sourcing process in general, and in the colour matching process in particular, range from simple methods of standardising illumination by light booths equipped with equal sources of illumination, to spectrophotometers to eliminate the variables of viewing and colour perception, and computer-aided methods for colour matching and numerical evaluation of colour differences.

2.7 Computer-aided colour matching

Colour matching systems incorporate much of the information that is kept as physical shade banks, colorant shade cards and the experience of a colourist when visual colour matching is performed. In the 1960s and early 1970s when the first computer-based colour matching solutions were introduced to the dyeing industry, only a few mills had their own, adequate computer. In 1971, ICI in the UK offered a prediction facility to customers with an accurate instrument for measuring colour difference (Sule, 2002). Offering such a service today is still valid practice, but delivery methods have shifted towards web services where the client logs onto the dye makers' websites, transmits the reflectance values from his instrument and selects to obtain an appropriate selection of dyes, based on defined fabric properties. Today, when computers and colour matching software are no longer rare equipment at dye manufacturers, customers do not have to rely purely on this service from their dyestuff suppliers. As early as the 1940s, the first attempt had already started to use a combinatorial aid in the recipe creation process, but the need for several hours to calculate a single recipe meant that these solutions were not really accepted in preference to the manual and visual process. Since the first digital computers were not affordable in practice, it was an analogous device called COMIC I, used in 1958 by Hemmendinger and Davidson (Fig. 2.4), that made a colorant mixture computer available for broader industry usage. The time is now past when computers needed several minutes to calculate an adequate recipe; and when personal computers were introduced in the 1980s and no longer represented an enormous investment, the time

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2.4 Hemmendinger and Davidson's 1958 COMIC I (courtesy of Applied Color Systems ACS Inc., Princeton, NJ).

came when dye houses started to discover the advantages offered by so-called computer-aided colour matching (Fig. 2.5).

A lot of maths is obviously involved when machines determine what selection of dyestuffs needs to be mixed and in what quantities, in order to establish a best-case spectral match of the resulting reflectance and the defined target. The rules involved in the prediction are based on Lambert and Beer's law, as explained earlier, combined with the findings of Kubelka and Munk in the first half of the twentieth century. Together with the analysis of translucent and transparent materials, Kubelka and Munk evaluated and developed laws for mixing opaque samples, as in the case of textiles. In opaque systems of this kind, the reflectance consists of a ratio of absorption (K) over scattering (S). As the colorants used in textiles have negligible scattering properties in comparison with the material (the textile) they are applied to, the K/S ratio is sufficient to characterise the colouring dyestuff. The so-called single-constant Kubelka–Munk theory is valid for a single wavelength at a time, so the introduction of sufficient calculator resources and a spectrophotometer are mandatory for non-visual colour-matching processes.

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2.5 Datacolor CHECK™ portable spectrophotometer.

In order not to exceed the aims of this chapter, the works listed in Section 2.11 should be consulted to learn more about this subject. A fairly simplified summary of the complex maths involved can be described as follows. Beer and Lambert established the rules of the relation between absorption and colorant concentration. With Kubelka and Munk's observations about absorption and scattering versus the internal reflectance of opaque materials, a direct relation between a colorant's concentration and the resulting spectral reflection could be derived.

A few equations will facilitate explanation of the Smartmatch® technology in Section 2.7.2. Equation [2.1] below shows the single-constant theory of Kubelka and Munk, as used for textile dyeing:

$$\frac{K}{S} = \frac{(1 - R)^2}{(2 * R)} \qquad [2.1]$$

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where reflection (R) absorption (K) and scattering (S) are wavelength-dependent parameters. In textiles, K is represented by the absorption of the fibre KT and absorption of the dyestuff KF. As described earlier S is only defined by the textile material itself which results in the modified Kubelka – Munk theory:

$$\frac{K}{S} = \frac{(KT + KF)}{S} \qquad [2.2]$$

Equation [2.3] below shows Beer's law, where KF is proportional to the dyestuff concentration C:

$$\frac{KF}{S} = A \times C \qquad [2.3]$$

where A represents a wavelength-dependent absorption coefficient of the dyestuff, related to S, and C represents the dyestuff concentration.

If multiple dyestuffs are involved in a dyeing process, the absorptions are summed up as shown in equation [2.4]:

$$\frac{KF}{S} = A_1 \times C_1 + A_2 \times C_2 + \ldots + A_n \times C_n \qquad [2.4]$$

where n is the number of dyestuffs in the dyeing process, $A_1, \ldots, A_n$, are wavelength-dependent, absorption coefficients of the dyestuffs, related to S, and $C_1, \ldots, C_n$ are dyestuff concentrations. Equations like equation [2.4] are created for as many individual wavelengths as are available and suitable for individual calculations. At first a 20 nm resolution (between 400 nm and 700 nm) resulted in 16 equations, whereas today a 10 nm resolution with 31 equations is common technology.

2.7.1 Traditional methods

The success of colour matching lies in the availability of a bank of information about the colouring components to be used. Computer-based colour matching systems use so-called 'colorant databases' which represent individual concentration dyeing as 'rungs on a tint ladder'. Like the information acquired by a colourist for visual colour matching, information is collected about the relation between individual dyestuff concentrations and spectral reflectance (absorption). The relation between the theoretical and effective concentrations of each dyestuff, plus the substrate-dependent absorption and scattering behaviour of the textile fabric, allow the prediction of spectral reflectance data. This, in turn, is essential to calculate an approximation of the mixed colorants' reflection to the standard's reflection, in order to create a match. It follows that mistakes occurring during the creation of such a database, i.e. unrealistic representations of the dyestuffs' behaviour in laboratory conditions, will directly influence the accuracy of the match prediction results. Dyestuff

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makers spend a significant amount of money to provide their customers with data about their dyes, but since databases of this kind do not represent real conditions at the dye house, this will always be the least preferred solution and should only be used for exceptions and less frequently used dyestuffs.

The use of a spectrophotometer as the next step is where the visual matching process separates from the instrumental or computer-based process. The *K*/*S* values are calculated from the measured reflectance characteristics of each concentration of each dyestuff, depending on the wavelength over the visible spectrum. With the aid of the graphical representation of the theoretical vs. effective concentration, the verification of the prepared tint ladders is evaluated. The relation should result in the smooth building of the curve, with a clear tendency to linearity.

After the dye set preparation, the next task for a computer-based colour matching system is the calculation of the recipe itself. Irrespective of which of the four colour-matching tasks described at the beginning of Section 2.6 has to be performed, a spectral match is the ultimate goal. As for visual colour matching, the user of a computer-aided system might first consider which dyestuff he will provide for the algorithm to calculate the required concentration amounts. If there is no technical limitation that excludes specific dyestuffs from selection for the resulting formula, the user is better off letting the system decide which dyestuffs would fit. Based on the information contained in the colorant database, the calculations are done from the effective concentrations back to theoretical concentrations. This allows the effective concentrations found in a least-squares calculation (a mathematical optimisation technique to find an approximate solution for a system of linear equations that has no exact solution) to be used as a theoretical recipe output. The use of the least-squares method in spectral-matching algorithms comprises several limitations that users have attempted to overcome, e.g. by using weighted least-squares methods. Other methods were also introduced that are described in the literature by linear programming techniques. As mentioned, the result of a computer-aided colour matching operation is always a theoretical recipe only. The calculations done by the system are based on the characteristics of single dyestuffs and on the assumption that the individual relations of absorption and concentration are also valid when the predicted dyestuffs are mixed together.

2.7.2 Advanced methods – Smartmatch® technology

At first, only a few traditional dyers and expert colourists made non-disparaging comments about computer-based colour-matching systems. The disadvantage most often claimed by the majority of dyers was the obvious inability to take account of the interactions of dyestuffs. The previously mentioned Kubelka–Munk addition law of dyestuffs is based on the assumption that dyestuffs do

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not interact with each other, and a traditional computer-based system does not know the exact nature of that interaction. It might be that a specific red inhibits the development of a stronger yellow more than another red; and various concentrations of that red might have different effects on the development of that yellow dye. We normally notice that there is an influence when the theoretically predicted recipe turns out not to match the given standard. Of course, there are quite a number of influences on the practical results of a recipe, but even if we standardise every variable, we will observe that 2% of yellow dyestuff used certainly does not always mean 2% of yellow colour for the fabric. Equation [2.4] shows that absorption coefficients are represented by the dyeings of the so-called 'tint ladder' of each dyestuff. The relation from equation [2.3] is used to determine these coefficients. When theory meets reality, the problem lies in the fact that the dyestuff concentration *C* in that equation is meant to be the concentration of dyestuff on the textile material. When the calibration dyeings are created, only the concentrations used – e.g. 0.25%, 0.5%, 1%, – are known and the absorption coefficients are calculated based on these. Particularly with increasing amounts of dyestuff concentration, the concentration accepted by the fibre decreases. The fibre is not capable of absorbing and 'using' all the dyestuff offered. This results in the fact that the assumed absorption coefficients are no longer constant, but dependent on the dyestuff concentration. As a result, the additivity of equation [2.4] is not accurate, and so the quality of first-shot recipes has to be questioned. Based on this easily proven fact, we must assume that more or less every first-shot recipe prediction by a computer-based system cannot satisfy the expected small colour differences from the given standard.

In the early 1990s, the Swiss-based colour management company, Datacolor, introduced some revolutionary new mathematics to compensate for this theory–practice mismatch. The procedure of determining the discrepancy between theory and practice by performing a batch correction is done upfront by the Smartmatch® technology in the first-shot calculation. This method, which performs completely differently from common 'search and correct' methods for the improvement of first-shot results, is based on prerequisites, discussed in detail below.

Just as the visual colour matching colourist takes advantage of a recipe archive, a database is required consisting of recipes that have been used successfully in the laboratory and in production. The colorimetric data of the defined standard and the results from the laboratory dyeing or bulk production run need to be stored together with the recipe, to allow the system to determine the variance between the theory and practical results. For every recipe calculation, the program routine searches through the population of all available recipes with colorimetric standards and results information. Only those populations where a match of substrate and process is given are considered. Additionally, within a build population, only recipes that use the same dyestuffs

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as the 'planned' recipe are evaluated. Based on restrictive criteria relating to the colour differences between the standard and the obtained result, a sub-selection of dyeings is analysed with regard to their colorimetric data and dyestuff concentrations, in order to provide corrective information for the production of the actual recipe. The information obtained from 'the larger the better' population of previous dyeings results in corrective factors that are incorporated into equation [2.4]. Because the corrective action in the calculation of first-match prediction trials already incorporates historic and practical experiences of real dyeings, the error rate of traditional first-shot recipes can be significantly reduced. The errors, caused by the known ambivalent additivity of equation [2.4] and the unknown interaction of the dyestuffs used, as well as the influences of surface reflection of standard and substrate, are described by the collection of practical results. They can be quantified and proactively used to make corrective actions even before the first lab-dip is produced. One of the major advantages of Smartmatch® technology lies in its automation. Every recipe predicted by the Datacolor MATCH$^{\text{TEXTILE™}}$ or relevant predecessor software, that underwent a proper approval process by measuring the batch result against the given standard, is automatically incorporated into the appropriate population of recipes. In fact, this makes the system a self-learning tool to increase the accuracy of the predicted, first-shot recipes significantly.

Traditional 'search and correct' functions are certainly able to find the closest recipe of a similar shade from which to correct, but such systems do not correct for the aforementioned inappropriateness of additivity of the traditional Kubelka–Munk colour matching theories, or for the impending interaction of dyestuffs. A direct modification of the dyestuff with *K*/*S* values provided by the Smartmatch® technology is necessary to compensate for these deficits.

Traditional computer-aided colour matching systems allow for a 30–80% first-shot rate of acceptable recipes. It has been proven that the use of Smartmatch® technology can reach visually accepted first-shot results in up to 90% or more of predicted recipes. The quality improvement of this technology has been evaluated in several surveys and some results of a representative study will be mentioned here.

In a first analysis, the dyestuff concentrations of first-shot results based on traditional match prediction software were compared with results based on Smartmatch®. Both technologies had to prove their correspondence to the target recipe. Eleven polyester dyeings were created as target recipes, using three common dyestuffs, but with increasing dyestuff concentrations. The population used by Smartmatch® consisted of the relevant dyeings, but without the specific target recipes for each evaluation (see Table 2.4 and Figs 2.6 and 2.7).

The results show a reduction in the averaged concentration error from

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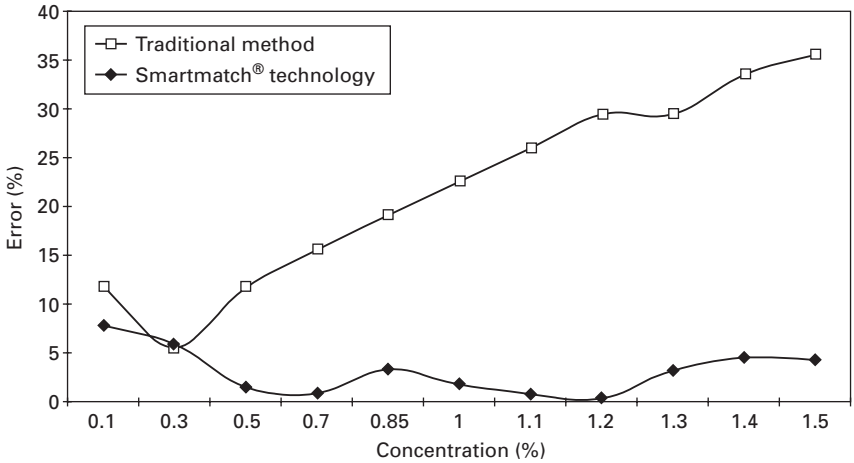
Table 2.4 Summary of Smartmatch® results versus traditional method on a trichromy

	Target recipe concentration (%)			Traditional method calculated recipes					Smartmatch® calculated recipes				
				Concentrations (%)			Results		Concentrations (%)			Results	
Dyeing no.	Yellow	Red	Blue	Yellow	Red	Blue	dC (%)	dE	Yellow	Red	Blue	dC (%)	dE
1	0.1	0.1	0.1	0.08	0.09	0.11	11.7	1.5	0.11	0.10	0.11	7.9	2.0
2	0.3	0.3	0.3	0.27	0.29	0.29	5.5	0.5	0.35	0.31	0.30	6.0	1.1
3	0.5	0.5	0.5	0.38	0.47	0.47	11.8	1.5	0.51	0.50	0.49	1.5	0.3
4	0.7	0.7	0.7	0.45	0.64	0.68	15.6	2.3	0.71	0.71	0.70	0.8	0.1
5	0.85	0.85	0.85	0.48	0.75	0.83	19.1	2.9	0.87	0.91	0.85	3.4	0.4
6	1.0	1.0	1.0	0.52	0.81	0.99	22.6	3.4	1.00	1.03	1.02	1.8	0.3
7	1.1	1.1	1.1	0.54	0.82	1.08	26.0	3.6	1.09	1.11	1.11	0.8	0.1
8	1.2	1.2	1.2	0.56	0.82	1.16	29.5	3.8	1.20	1.20	1.20	0.3	0.1
9	1.3	1.3	1.3	0.61	0.86	1.29	29.5	3.9	1.34	1.34	1.34	3.2	0.3
10	1.4	1.4	1.4	0.61	0.83	1.35	33.6	4.2	1.33	1.31	1.37	4.5	0.1
11	1.5	1.5	1.5	0.64	0.82	1.44	35.6	4.4	1.46	1.36	1.50	4.2	0.4
					Averages		21.9	2.9				3.1	0.5

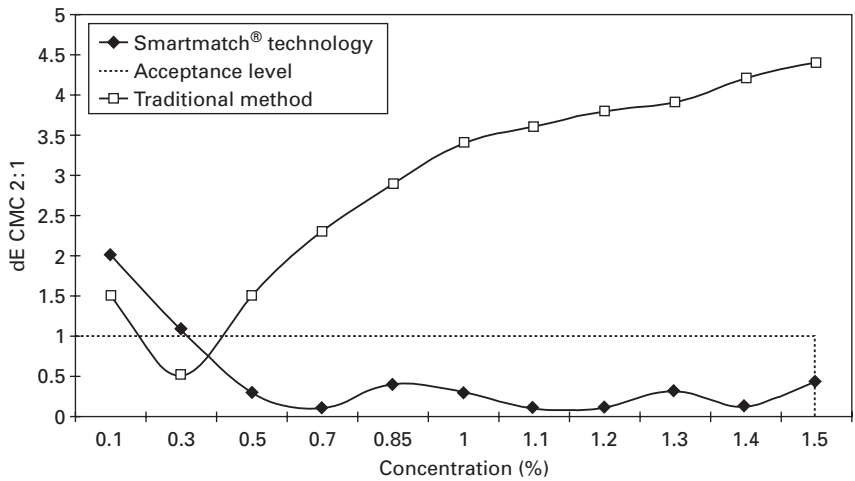
dC, proportional deviation of the dyestuff concentration, calculated from the addition of the individual, absolute concentration differences between calculated recipe and target recipe in relation to the total concentration of the target recipe.
dE, CMC (2:1) colour difference of the theoretical colour coordinates from the calculated recipes to the target recipes.

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2.6 Graphical representation of the concentration deviation for a trichromy.



2.7 Graphical representation of the colorimetric difference for a trichromy.

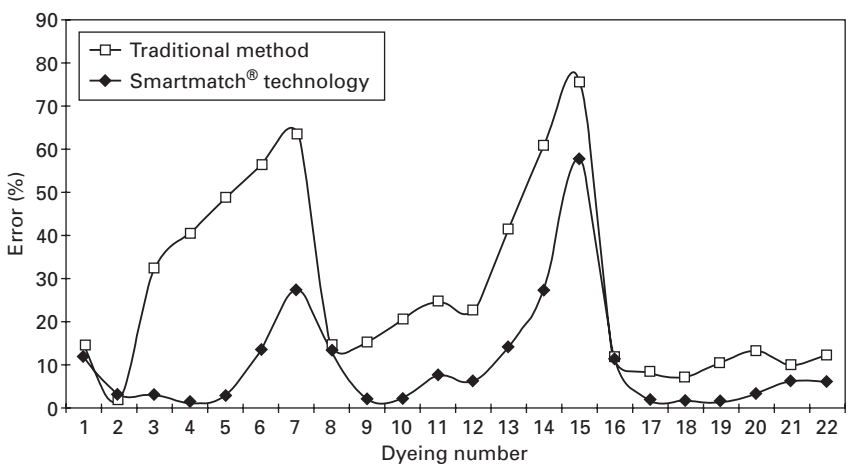
about 22% down to 3%. With increasing dyestuff concentrations, the well known tendency towards decreasing quality of first-shot results based on the traditional method is well represented by the graphs in Figs 2.6 and 2.7. On average, the results based on Smartmatch® do not show this effect. Dyeing no. 11 shows a large discrepancy between the calculated yellow and red dyestuff concentration and the target recipe using the traditional method; this deviation is eliminated by the recipe that used Smartmatch®. On average,

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'learned' behaviour about individual dyestuffs allowed a six-times-smaller colour difference, and about 80% of the results fulfilled the practical visual acceptance tolerance of dE CMC = 1. The traditional method was only capable of meeting this critical barrier in about 10% of the dyeings. The results of first-shot predictions with Smartmatch® improve as more information is made available, from which the system can learn. Dyeings 1 and 2 did not pass the visual tolerance levels because for these calculations an insufficient number of dyeings was present in the population used.

Another evaluation using four dyestuffs – where three were the same, but in increasing concentrations and with a shading component as the fourth dyestuff – proved the results of the first study and showed additional, interesting observations. Figure 2.8 shows dyeings 1 to 7 with a yellow shading component, 8 to 11 with red as the shading component, 12 to 15 with orange as the shading component and 16 to 22 using blue for that purpose. It is clear that in most cases the tendency to predict inaccurate concentrations increases with larger concentrations of the shading component. Even the recipes calculated with Smartmatch® show that effect in dyeings 7, 11 and 15.

It is interesting to observe that although the concentration deviation from the target recipe is quite high, as for example in dyeing 15 (Fig. 2.8), the resulting colour difference of the Smartmatch® prediction is small enough to pass the visual acceptability of 1 dE CMC (Fig. 2.9). It is consequently unreliable to use only the comparison of the concentration error to describe the quality of a computer-based colour matching system. Many different recipes can be used to reach a visually acceptable result, as long as a full spectral match is not demanded. The expected slight increase of metamerism with alternative recipes might be acceptable if other benefits are gained. A detailed view of the



2.8 Graphical representation of the concentration deviation for a quadrichromy.

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individual dyestuff concentrations of dyeing number 15 shows another interesting capability of the Smartmatch® technology, (Table 2.5).

Both prediction methods have increased the amount of yellow and red dyestuff, whereas the amount of orange was significantly reduced in comparison with the target recipe. However, only the result of the Smartmatch®-based recipe shows colorimetric differences clearly below the visibility tolerance. The cost savings obtained by using only half the amount of orange dyestuff could have an important effect on the costs of the final bulk production, so this recipe would be among the choices made by dye house manager to run a production lot for that target.

None of the recipes using traditional methods for this quadrichromy were able to pass the acceptance level, whereas the Smartmatch® method returned 90% of accepted first-shots (Fig. 2.9); this would mean no further laboratory dyeings with related costs. This example shows that providing that an appropriate number of recipes in a suitable population is available, not only can the lead time be dramatically reduced, but the supplier will also have a tool that allows him to predict recipe costs for various alternatives. He can be assured that the predicted quality standard can be met, although he will not use the quantities of dyestuff that he may be given in the form of a standard recipe, with an engineered standard.

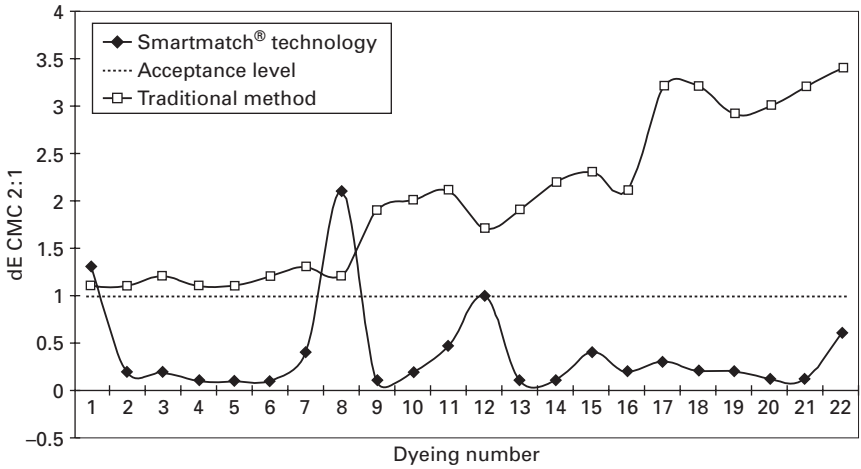
2.8 Opportunities for the supplier

In today's time-, cost- and quality-critical apparel industry, it is almost impossible to imagine a supplier who has not established computer-based colour matching in his dye house. The visual colour-matching methods described earlier – based on experience, estimates and visual evaluation – have been widely replaced by computer-aided colour matching systems, based on the optical and colorimetric properties of colour standards, dyestuffs and substrates. The economical advantage is undoubted since the benefits of this technology include reduced raw material costs for dyestuffs and auxiliary items, and also reduced lead times and production costs. Recipes to transform designers' colour inspirations more quickly and more reliably with regard to metamerism and the fastness properties of coloured fabric, are made available

Table 2.5 Detailed dyestuff concentration of dyeing number 15

	Concentrations(%)					
	Yellow	Red	Blue	Orange	dC (%)	dE CMC
Target	0.2	0.30	0.1	2.0		
Traditional	0.26	0.58	0.09	0.37	76.0	2.3
Smartmatch®	0.28	0.51	0.09	0.80	57.7	0.4

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2.9 Graphical representation of the colorimetric difference for a quadrichromy.

faster and on a more flexible basis. However, as industry standards are developing and regulations become tighter, market demands are increasing, but since textile dyeing is generally not considered a really attractive field of employment, the number of experts is shrinking, and so technological advantages need to be used to help suppliers fulfil expectations.

Based on the good results obtained for the improvement of traditional first-shot results, several additional fields of application have been evaluated for this technology. Along with fashion trends, there is a growing demand for increased functionality of textiles, which has a direct impact on the general production process. The added value for the final goods is resulting in greater demands on the coloration process. However, many of the finishing processes for treating textiles have an impact on the colour of the material. There are not only reversible effects such as thermochromativity, when colorants are exposed to temperature; but also non-reversible changes can occur to the colour applied with such intense effort in the dye house, as for instance when processes such as flame-retardant finishing are mandatory for the final use of the material. Since after this treatment no further coloration processes occur that could change a modified colour back to its original, a pre-prediction of the colour change is required at the dye house stage, which represents a kind of off-shade matching with regard to the defined colour standard. Physical finishing processes mainly influence the lightness and chromaticity of a shade, which can be reworked to a certain extent. To reduce an increased L* coordinate, emery or napping processes are used to create more scattering on the surface, which results in a darker, less bright appearance. Chemical processes such as those used for flame-retardant preparations have an impact

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on the whole colour, so they are almost impossible to change back. By using a computer-aided colour matching system with Smartmatch® technology, a recipe can be created that can be described as a 'correct off-shade match', because the system has been fed with the practical results of treated samples and can therefore analyse the difference between traditional tint ladder results and the effect of the flame-retardant finishing process.

Another major benefit for suppliers using self-learning technology of this kind is the ability to build up a better correlation between their laboratory scale samples and the results of bulk production. Companies that do not monitor their production colour results based on colorimetric information will quite often discover that their real problems only begin once they try to reproduce an accepted recipe for a defined colour standard on a real production run. The influence of the dye machines, different processes and treatments cannot be underestimated. Needless to say that the cost of several incorrect production results is much higher than the effort of keeping historical records of results and investment in proper usage of an expert colour-matching system.

The field of colour matching today also includes aspects of production correction and optimisation. Some companies think that once a colour recipe is available, they are more than halfway down the road to obtaining their fabric quickly from the dyers' plant. Before the availability of computer-based, highly sophisticated recipe- and production-optimisation packages, the electronic part of the recipe creation was done at this stage. All the sophistication needed to produce perfect bulk production from the predicted laboratory swatch depended on the dye house manager's expertise and know-how – and quite often on his ominous 'black book' where he kept notes of all his experiences of various dyeing procedures, treatments and tricks. Several experts still describe textile dyeing as an art or sometimes even magic, but fortunately most of the magic spells are simply based on physical and chemical reactions. These reactions and interactions can be described in tables, and by rules and formulae in which the dyes and chemicals used, the different machine types and also customers' demands are stored. Aspects such as the steadily growing amount of textile dyeing and finishing oriented towards high-quality goods, the requirements of special fabric treatments, ever-increasing tighter environmental regulations and delivery times, can only be handled properly and cost effectively if a relational database system is in place that every exception and reacts automatically to calculate the appropriate production recipe and dyeing instructions. Without needing a person to think about 'What has to happen, when and if?', every dye lot can be assured to run under optimal conditions, especially if all the calculated data are transferred to the machine-driving supervision systems, colour kitchens and chemical dispensers. As in advanced methods of colour recipe creation, a database incorporating all the secrets of the dye house manager's 'black book' can run

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completely autonomously. In addition, the positive benefit for customers of such dye houses is that they can trust the predicted costs, delivery dates and quality much more reliably, because even before the first batch is dyed, a simulation process can be run to evaluate every detail.

2.9 Opportunities for the fashion industry

As described in Section 2.5, some apparel and retail brands are still quite disconnected from the colour-matching process. A noticeable barrier separates the creative 'dry business' from the challenges to convert the results of this creativity into goods to fill the shop's racks – known as the 'wet business'. There is still a long way to go to make 'a right-side creative brain' understand the benefits of 'left-side brain technology', as a loss of feeling, touch and intuitive ideas have become associated with colour measurement equipment. Not that the author is suggesting that every designer should use computer-based colour-matching systems, but he should make use of the benefits and possibilities offered by these solutions to make his life easier. A designer wants to ensure that his colour ideas can be produced quickly and without the need for endless trials and boring meetings with technical guys because a certain flashy green might not be achievable in a wide variety of mixed materials for next season's trend-setting sweater. Imagine a designer with computer-based aids to transfer his ideas onto the computer-aided design (CAD) systems screen for further processing into product lifecycle management (PLM) systems. The colour shown on his calibrated monitor is not only true colour, but it is also evaluated as matchable with dyestuffs suitable for the individual material to be used. From the colours that have passed the designers' and colourists' critical selection, various supply chain partners can receive the objective colour standards directly in the form of a digital colour fingerprint. There will be no discussion that the standard is too small to be measured or that it is of a different material from the final fabric. The dyer will simply receive the reflectance data from the representation on screen and let his Smartmatch® system work for him.

Since computer-aided colour matching allows us to capture the master dyer's methodology and helps dyers around the globe to handle the significant differences between colour theory and real-life practices, such systems can provide very appropriate results in the early stages of colour design and approval processes. Along with the intangible and emotional importance of colour, it should not be forgotten that a fashion idea is only successful for any member of the apparel supply chain if it can be successfully and quickly converted into a tangible fashion item, and, of course, at reasonable cost.

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2.10 Future trends

One major objective of the apparel industry is to express fashion through colour, since consistency and quality of colour are perceived as value-adding or value-defining properties of the product. From the retail or brand point of view, valuable time is spent creating colour ideas and it is becoming more and more common for the specifier to take care to provide the most suitable colour standard to his partners in the supply chain. Suppliers have long been using tools to streamline the traditional process of lab-dip creation and trials, until the final colour expectation is met. Their customers are also taking advantage of existing solutions for global colour communication. The link is well established between digital sampling and cost-effective, computer-based colour matching, with the resulting speed to market. However, there is always room for improvement.

There is huge potential for increased quality, reduced cycle times and cost reductions in the integration of data and workflow between the actual dye lot creation and order processing systems. Fully automated dye houses with machine supervision systems that receive the information needed without any paperwork and produce cost pre-calculations and end-result reports, are increasingly to be found among European and North American suppliers. The disadvantage of their higher production costs can be counteracted by faster and more reliable reaction to customers' demands for high quality. The seamless interaction of different data platforms is a challenge confronting suppliers using traditional colour matching systems, as for providers of PLM systems and laboratory and production-machine suppliers. The precision of laboratory machinery is constantly increasing to keep pace with tighter colour tolerances every year. The colour quality that can be delivered can only be as good as the weakest piece of equipment is capable of supporting. Laboratory-scale reproduction of numerical colours is among the essentials for accurate and fast colour production.

User-friendliness is not simply a buzz-word with regard to computer-based technology. It should not be necessary to employ highly skilled, computer-specialised and industry-knowledgeable experts when introducing new software systems. The design of the user interfaces, and even more important the functionality and clear relation to the industry's workflow are among the major factors determining the acceptance and success of such solutions.

As the technology described in this chapter facilitates working with digital samples and colours by numbers, it is essential that proper communication methods for such data are established throughout the entire supply chain. E-mail data exchange is capable of handling current data volume and appropriate reporting tools allow each user to generate the information he needs. However, in the very near future, database access will be required that exceeds a

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company network, in order to streamline data exchange even further. Accessibility to information that is no longer dependent on a physical location or on locally installed software is mandatory for employees along the supply chain who travel. Logging onto a web page while abroad to receive colour approval statuses, or to inform a dye house manager about production will soon be common technology. With all this flexibility and independence, however, it must always be recognised that every solution depends on its method of delivery. We have not yet reached the time when a fully automated dye house can maintain its productivity on the availability of Internet access. A certain 'hype' for web-based solutions is clearly noticeable within the apparel industry, but the Internet today still has no guarantee of 24/7 availability. However, wherever periodic disconnection from the web causes no delay to decision-taking or process steps, it will certainly be the platform for future solutions.

2.11 Sources of further information and advice

Within the limitations of this chapter, it was not possible to explain in detail all the basics and fundamentals of colour theory, and it is therefore advisable to contact the useful sources of information given below, as well as consulting the references listed.

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- www.aatcc.org
- www.VDTF.de
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3

Computer-aided design for yarn

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3.1 Introduction

This chapter tells the story of a group of researchers who determined in the early 1990s to approach the computer-aided design (CAD) of textiles from the opposite direction to that previously adopted by researchers or developers in this field. Despite over a decade of endeavour this project remains work in progress and due to the complexity of the subject and the reactionary nature of the industry it will probably continue as such for some time to come. The different approach taken by this group can be summed up quite simply. When a fabric is to be designed and then produced, it is first necessary to choose a suitable yarn with the required aesthetic and mechanical properties. It is therefore logical that if an accurate computer simulation of a fabric is to be produced, we should begin with the accurate simulation of the component yarn. As with all simple statements of concept, the implications of this statement are far reaching. The chapter will try to explain these implications and the reader will be asked to carry out some simple exercises to help their understanding of the process requirements. Only by getting CAD for yarn simulation right will CAD for fabric simulation be accurate and consequently CAD for apparel simulation will become the useful and necessary tool that it promises to be.

3.2 Background

The development of fabric CAD simulation packages started seriously in the late 1970s and early 1980s in parallel with the increasing power and availability of personal computers. The authors can remember the early development of the Scotweave system taking place on a BBC B1 with less than one-hundredth of the processing power of a modern laptop and in the very unfriendly MS-DOS environment. By the early 1990s there were a plethora of such systems all offering or claiming advantages over each other. The Milan ITMA (International Textile Machinery Association) exhibition of 1999 was the

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first with a hall dedicated entirely to CAD systems. Unfortunately, by the Birmingham ITMA of 2004, many of these had disappeared and discussions with senior staff of remaining companies reveal that the market is becoming ever more difficult to compete within.

On the other hand, many fabric manufacturing companies have invested in systems that quickly became unused or obsolete; sometimes due to the loss of trained staff or because the system could not provide the full range of functionality, usability and accuracy required. From the earliest stages of development, one of the demands from design and manufacturing companies was for yarn simulations to be included. However, as most of the systems had been developed using two-dimensional (2D) fabric simulations, the only option then was to superimpose scanned-in or painted 2D yarn images on top of the simulated fabric structure.

> Exercise: Find a couple of yarns that you find attractive. Now try to draw these yarns using paper and pencil or by computer. Compare the drawn images with the actual yarns. Are you satisfied that the drawn images are successful and how do you think they might be incorporated into a fabric construction?

That little exercise will help you understand the problem at its basic level.

A question to be considered at this stage is why those who were developing the early CAD systems chose to start at the fabric stage and not with the same building block used by the fabric producers – the yarn. The answer is quite simple. Symbolic notation methods for fabric structures were available and commonly used throughout the textile industry for over 200 years before the advent of personal computers. Indeed, the Jacquard loom is considered by many as the predecessor of the computer and operated a complex shedding mechanism in response to a manually prepared notation. Early developers, therefore, already had manual simulations to use as a base reference. No such notations were available for yarn structures and their mechanical properties were relatively poorly understood despite the sterling efforts of researchers such as Treloar, Hearle, Martindale, Goswami and many others. It is sobering to think how much progress they might have made had they access to modern high-powered computers. As it was, much of this work went unheeded as the captains of industry could not perceive its usefulness, but the then existing body of work provided a starting point for the YarnCAD team as it was first formed through a grant from the Engineering and Physical Sciences Research Council (EPSRC) in 1993.

3.3 Early stages

The aim was to make a computer model that would accurately simulate a

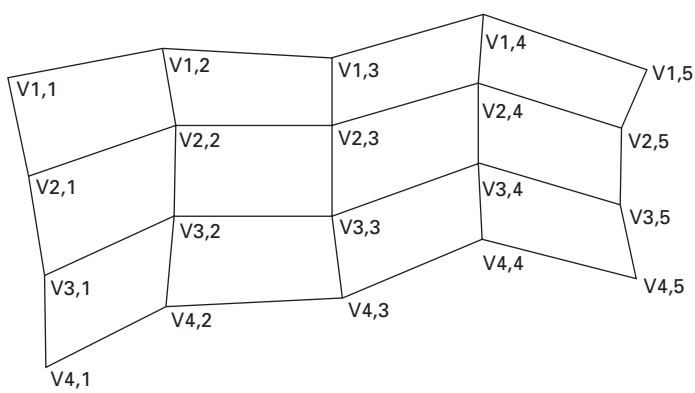
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flexible fibrous assembly, such as a yarn, in a 3D form and that would have sufficient mechanical property accuracy to allow it to be incorporated accurately into a knitted or woven fabric simulation. Consequently, a great deal of complicated mathematics is involved and for the reader who wishes to study these carefully, references will be given at each stage; however, in this chapter only an outline will be given.

3.3.1 Yarn appearance simulation

Much of the early thinking is given in a conference paper by Liu *et al*. (1995), though a more accurate explanation including the use of a compression model to improve the accuracy of the simulations is given in Harwood *et al*. (1997). It was necessary to generate the strand shape correctly and so it was assumed that the strand had constant linear density (count) and constant tensile force along its entire length. Thus, the simulated cross-sectional shape will be the same throughout its length and the centre line of a strand will maintain a constant distance from the centre of the yarn twist. Each strand in a yarn will follow a helical route along the axis of the yarn according to the established geometrical models (Hearle *et al*., 1969; Goswami *et al*., 1977; Hearle, 1989).

A quadrilateral-mesh method was employed to generate the strand surface as a wire frame; a mesh of this type is a rectangular array of adjacent facets, each of which is composed of four vertices, as shown in Fig. 3.1. The facets are formed from the neighbouring vertices in the array. Therefore, an array of M rows and N columns produces an $M - 1$ by $N - 1$ mesh of quadrilaterals. In Fig. 3.1, M is 4 and N is 5. Each quadrilateral is one facet. In creating the mesh several aspects had to be pre-defined.



3.1 A quadrilateral mesh.

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3.3.2 Mesh size

The size of mesh directly affects the smoothness of the surface generated and is also an important factor influencing the texture simulation of the surface. Theoretically, the smaller the meshes are, the smoother the surface will be. To a certain extent, a smoother surface is closer to the reality of the majority of yarn appearances. However, the mesh size is practically restricted by the hardware used such that, when the mesh size defined is too small, the array dimension would not be enough to hold all the vertex data or even if there was no problem for the array dimension, the speed at which the surface is created would become unacceptable. A compromise is therefore necessary between the accuracy of the strand shape and the display effect.

3.3.3 Cross-section of the strand

In the case of conventional multi-strand yarns, each strand is simulated as helicoids whose cross-section in the tangent direction is a circle, which is an accepted approximation in yarn modelling. Naturally, the intersection of the horizontal plane with the helicoids produces a kind of ellipse, the major and minor axes depending on the specifications of yarn twist. In order to provide more realistic simulations it was quickly realised that the cross-sections could not be circular and that a study would have to be carried out in order to define how strand cross-sections changed with degree of twist and other factors.

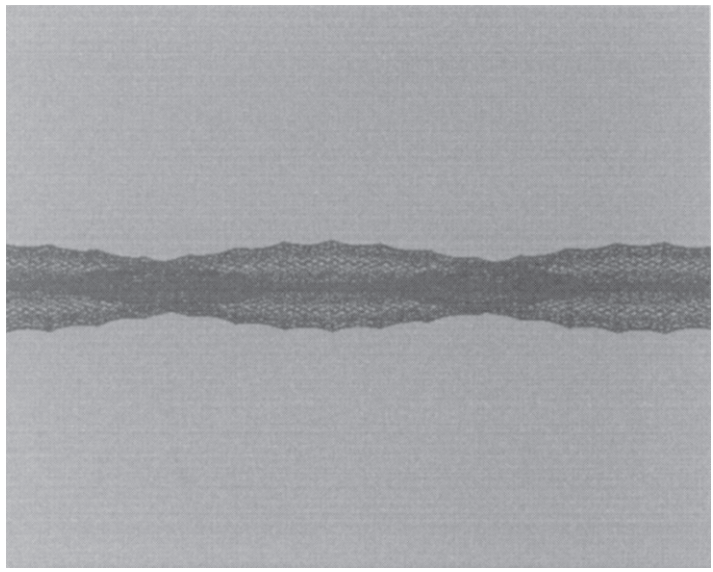
3.3.4 Vertex array

The vertex array is created to contain the actual x-, y- and z-coordinates of all the vertexes in the mesh surface. In order to start the simulation of the strand surface, the vertex array must be assigned the 3D coordinates that are generated from the initial definition, rotation and translation. Figure 3.2 shows a mesh surface.

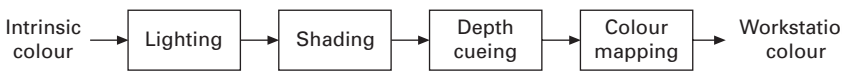
3.3.5 Colour

Colour rendering was used to reveal the yarn texture. When colours are initially assigned to each strand, they are called intrinsic colours. In order to get more realistic images the intrinsic colours are organised to pass four stages of rendering as shown in Fig. 3.3. Together with the quadrilateral facets arrangement, colour rendering was also used to simulate the orientation of the fibres of which the strands were comprised.

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3.2 Mesh surface.



3.3 Colour rendering.

3.3.6 YarnCAD system

Using the strategy described above, a first version of the YarnCAD system was produced using C language with the PHIGS graphics routine on a Sun platform. At that time, the Unix operating system was considered best for simulation work of this type. As we will see this had to change. Based on the geometrical model, the input specifications of the yarn included: yarn type (spinning system); yarn twist content and direction for both single and plied yarns; number of strands, linear density of strands and specific volume of fibres. When these specifications were input, the system then converted the geometrical structure of the yarn into an array of quadrilateral facets representing the surface of the strands involved. The data of the vertex coordinates were passed on to the yarn modeller to produce the simulated yarn appearance with a simulated yarn texture as shown in Fig. 3.4.

Thus ended the first stage of YarnCAD development. What set this work apart from anything else that existed at that time was the ability to simulate from manufacturing specifications and to be accurate when compared with the real yarn produced from the same specification; in addition, there was the ability to manipulate the simulated image using the arrow keys on the

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3.4 Yarn simulation.

keyboard or the directional buttons on the interface to show the true 3D nature of the simulation. However, at this stage the team had also carried out a wide ranging survey of the industry in order to find out how the yarn design process worked and what effect a CAD system would have on the process.

3.4 Survey of the industrial process

The researchers working on the project in the early stages felt that it was important to find out how the yarn design process worked within the industry and how a CAD system might improve this process. It has to be stated from the outset that the findings of this survey were surprising and rather disappointing. Companies were approached by questionnaire and interview. As would be expected the questionnaire return level was very low and revealed little. On the other hand, the 14 interviews that were carried out revealed a great deal and much that was worrying for the health of the industry and for the educationists involved in textile design programmes. In the first place, the various roles involved in the yarn development process were identified and it was found that design personnel were excluded from most of the more significant roles and certainly from any of the technological roles. Table 3.1 shows the roles involved. Only one of the 14 designers interviewed had any access to yarn production or sampling machinery and had to work through the technician in order to translate ideas into samples. Most designers in yarn-producing companies were not in any way involved in the development of the yarns but rather in the design and sampling of fabrics and/or garments, and the presentation of ranges to customers. Next, it was necessary to try to find out how the yarn design process worked and to identify the particular loops that caused hold ups and that might be improved by the interjection of an effective YarnCAD system. After much painstaking analysis the process model shown in Fig. 3.5 was produced. Inspection of this will enable the reader to see just how often a design can be turned down after a long period

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Table 3.1 Roles involved in the yarn development process

Yarn analysis and identification
Idea and sample specification generation
Yarn prototyping and sample production
Colour and trend analysis*
Colour and trend forecasting and presentation*
Sample book design and presentation*
Presentation preparation*
Customer presentations*
Exhibition presentations*
Sales
Marketing
Sourcing of materials and components

*Designer involvement.

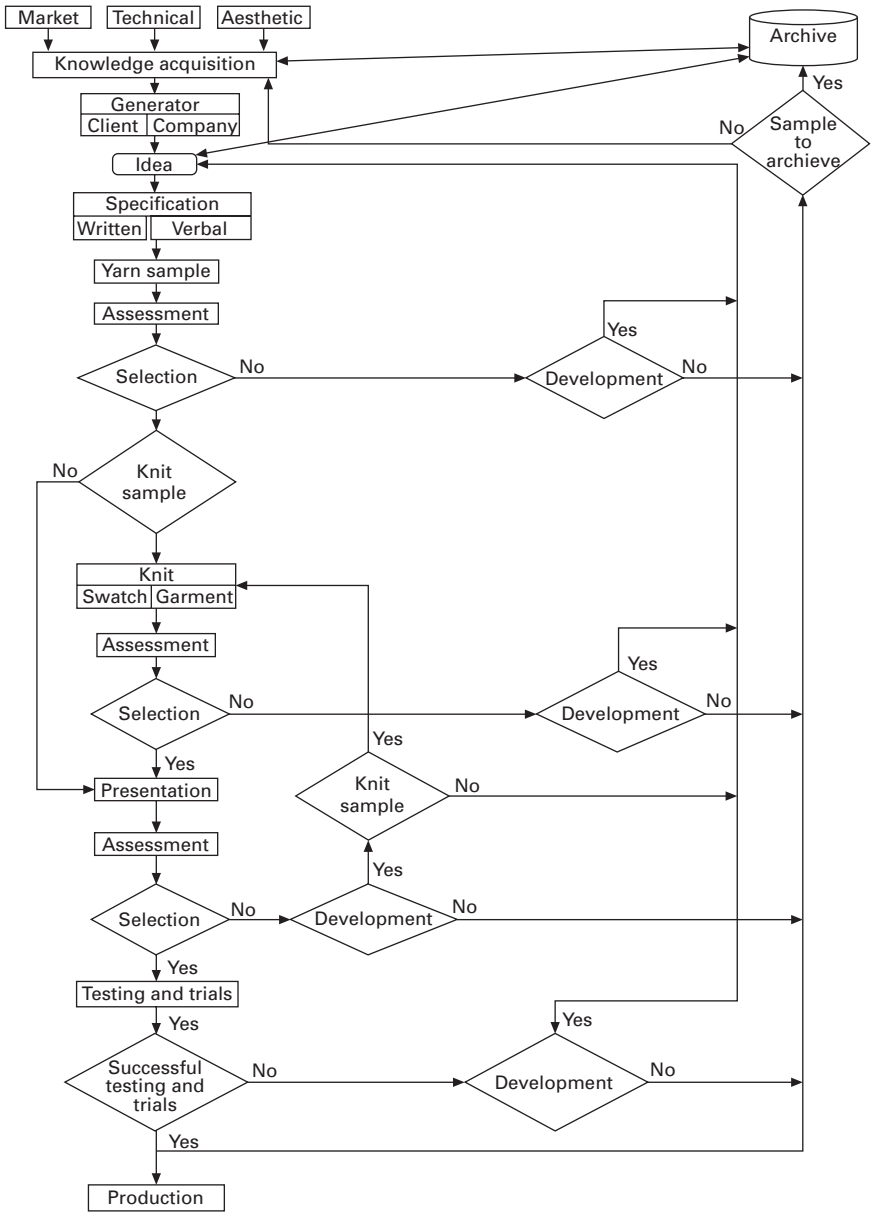
of development and if we consider the production times, component procurement, lead times, etc., we realise why the process from concept to product can take a minimum of weeks and more often months or longer. Any system that could reduce the timescale, and more importantly empower the designer, would have to be welcomed by the industry. We will come back to this later in the chapter. Suffice it to say at this point that the designer/technologist/manager interfaces were found to be disappointingly fragmented, even more so than the team had been expecting to find, and the comment made by one industrialist that 'the industry was not ready for a system of this type' was difficult to comprehend. Unfortunately, many of the companies surveyed no longer exist and with the trend towards fast fashion and mass customisation increasing, it would seem obvious that the industry will soon be ready and probably calling for such a system to be available.

3.5 Further development of YarnCAD

A second grant had been provided by the EPSRC to enable the further development of the system. Changes occurred within the team of researchers and, in particular, there was a strengthening of the mathematical modelling capability of the team grant enabling the development of more complex and accurate fundamental mathematical models underpinning the system. As stated earlier, this chapter will not go into the mathematics but the papers referred to will enable those who wish to avail themselves of the theory.

Other systems were trying to introduce yarn simulations at this time and some even tried 3D simulations, but what was shown looked more like toothpaste streams than yarns and were certainly not convincing. The same sort of effect can be seen today in some of the fabric 3D simulations that try to show the passage of the yarn through warp and weft or courses and wales

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3.5 The yarn design process.

structures. Until the yarn looks accurately like and acts accurately like the actual yarn these are not likely to impact strongly on the industry.

Exercise: Take a length of ordinary two-strand yarn and hold between the thumb and middle finger of each hand. By rolling

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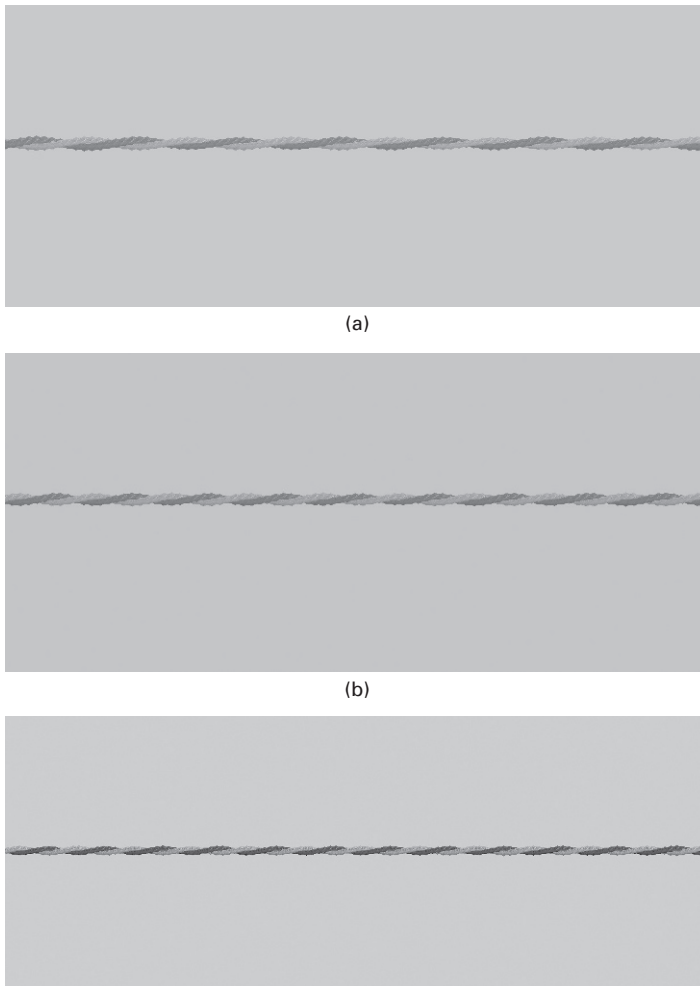
each end of the yarn between your fingers put more twist into the yarn, then take it back to the start point and take twist out of it in the opposite direction. Please also try to observe what the twist direction is (*S* or *Z*, for clockwise and anticlockwise, respectively).

By carrying out this simple task you should be able to observe that the yarn becomes leaner and more tightly compacted as twist is increased and bulkier and less tightly compacted as the twist is reduced. A theoretical model was developed (Grishanov *et al.*, 1997) and tested against real yarns of varying twist levels. Many samples of the latter were painstakingly prepared by encapsulating different twist level yarns in a resin after carefully placing them into specially designed capsules. Cross-sections could then be cut and the varying levels of strand compaction observed and measured. The results were then compared with the predictive model results and an acceptable level of correlation was obtained and therefore the model was incorporated into the YarnCAD system. Figure 3.6 shows the same count of yarn at three different twist levels to demonstrate the effect of the compression model.

Towards the middle of 1997, the team realised that if the system as to be acceptable to the industry in the future then the platform would have to change from Unix to the more commonly used Microsoft operating system. This was a rather lengthy process and the opportunity was taken to provide a more user-friendly front end which will be discussed later. Collaborators in the project at this stage included Cis Graphik & Bildverarbeitung Gmbh of Germany. This company had a commercial CAD system that provided excellent 3D fabric simulations and allowed the input of yarn irregularity/unevenness values; however, their yarn simulations were achieved mainly by scanning and did not have the realism of YarnCAD nor the possibility to create from manufacturing specifications. Cis also used the Unix platform and decided not to swap to Microsoft. Unfortunately, they no longer appear to be in this market.

One piece of valuable information that was obtained from the industrial survey was that the system would never be acceptable to the industry unless the yarn could be knitted into an accurate swatch and therefore a knitting module was added to the software by Dr Grishanov. This module required information on the bending characteristics of the yarn and thus another predictive model was required which was tested against the results from a KES-F bending tester for real yarns. This was successfully carried out and Fig. 3.7 shows the plain knit swatch of a simulated yarn in three views. In many ways, this is the most exciting part of any demonstration of the system and proves the true 3D nature of the simulations. In addition, in many cases the designer may use the reverse of a knitted structure as this may have the most desired effect.

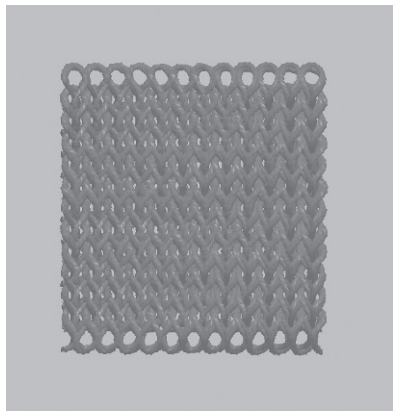
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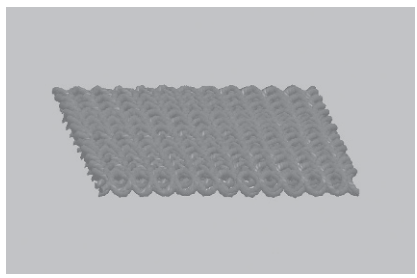
3.6 The same count of yarn at varying twist levels (a) 75 turns per metre (tpm) folding twist; (b) 100 tpm folding twist; (c) 125 tpm folding twist.

In 2003, grants were awarded by the EPSRC to enable teams at De Montfort University and the University of Leeds to investigate collaboratively the structure-dependent colour properties of melange yarns. Melange or mixture yarns are those made by the mixing, within the same strand, of fibres of varying colours from as little as 2 or 3 to 12 or more colours. Many attempts have been made towards solving the problem of providing a mathematical model that would be able to predict the colour of a yarn from its technical parameters (Townend *et al.,* 1964a, b; Bishop *et al.*, 1992; Sokkar *et al.*, 1992), but as yet there has been limited success. Even fewer attempts have

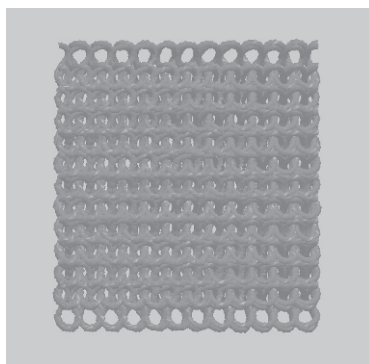
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(a)



(b)



(c)

3.7 (a) Technical face of fabric swatch; (b) fabric swatch flat and turning over; (c) technical back of fabric swatch.

been made on the development of industrially sound CAD systems for melange yarns. One example was a BRITE–EURAM funded project entitled 'Computer Aided Simulation of Textile Special Yarns for the Spinning Industry'. However, this suffered from major disadvantages such as the adoption of a 2D approach to the simulation of yarn structure which will not give realistic yarn images

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and will be difficult if not impossible to incorporate into a 3D fabric simulation. Also, the images produced suffered from incorrect presentation of the yarn colour composition.

As stated earlier, the front end of the system was much improved at the stage of changing platforms from Sun (Unix) to PC (Windows), but the team still felt that some improvement could be effected in terms of the usability. The authors decided to combine this with a more general study of the technologist/designer interface in the yarn development process. An experiment was designed requiring individuals to use the system to design their own yarn and then to try to simulate a given real yarn. The methodology used to capture and analyse the data obtained is known as 'protocol dialogue analysis' or the 'think aloud method'. This simply means that the subject is asked to articulate their thoughts as they carry out the task. Twelve participants took part in this exercise, each having a design or textile technology background and education. This resulted in many pages of statements which had to be refined and coded in order to discover trends in problems, misunderstandings, misinformation, poor navigation, etc. in the system. The main issues will be discussed here as bullet points but we will stick to the yarn design matters and ignore the more general navigation matters that were also a part of the study.

- The first input parameter that caused problems to the participants was that of which type of yarn did they wish to create. They were given the choice of: 'woollen/condenser' spun, worsted/roller drafted and cotton spun. Of the twelve participants, only one was confident in answering this. Rather disappointing when we consider the backgrounds of the subjects but it made us realise that some form of image would have to be provided to ensure that users would be able to make a correct choice.
- The next input parameter that caused problems was linear density. It had been decided that the interface would use 'Tex' as the most common count system. However, not only did we find that more of the participants preferred 'metric' or 'worsted', we also found that the understanding of the count systems was generally poor and that knitters were much more comfortable when given a choice of a count range that would suit a particular gauge of knitting machine.
- If linear density had proven surprisingly difficult then twist was even more challenging for the subjects. Only one had any idea about the relationship between linear density and twist content at the single strand level and, more surprisingly, very few had any understanding of the use of different twist directions. It has therefore been decided that the interface will offer the choice of: hard twist, normal warp, normal weft, hosiery and soft hosiery.
- Another surprisingly difficult decision area among the subjects studied was that of the folding twist. It has been decided to simply offer the

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choice of a hosiery twist which is 0.5 singles twist or a balanced twist, which is 0.608 singles twist. Of course, the user will be able to alter the default values for customisation purposes and for yarns comprising more than two strands.

- The original system interface also offered packing factor as an input variable. However, this is not a commonly used term in the industry and so descriptors such as lean, bulky and very bulky will be offered.
- The original interface also offered coefficient of variation (CV) of irregularity as an input and this will still be offered although it has been found that few users really understood what this was. It should be the CV figure obtained from a standard evenness tester such as the Zellwegger Uster Tester. An average default figure could be used as a default value but this could be altered to allow the effect of unevenness to be observed.
- The input parameter used in the original interface to identify the fibre type was the specific volume of a fibre (g/cm^3). However, this was an unknown to all the subjects and so the future interface will offer a choice of common natural and synthetic fibres and default to the relevant specific volume value.

Exercise: When you are going about your everyday business, try to identify the likely yarn type and fibre composition of the various articles of apparel that you observe on passers-by or in the shops. Good, young textile and apparel technologists and designers have always made use of this form of self-training.

3.6 Future trends

The project started as a tool to be used by the yarn design and manufacturing industry in order to reduce the lead times involved in the design of new yarns. It quickly became evident that this could also be a designer empowerment tool and, very soon after that, it was realised that it would become a very effective sales tool. Nowadays, a designer visits yarn fairs such as Expofil and Piti Filatli to see the yarn samples on offer from the various yarn manufacturing companies. To a certain extent the designer is pushed towards accepting something from the pre-determined product range of the yarn manufacturing companies. The designer can, of course, enter into dialogue with the sales personnel and this is the stage at which the yarn design process starts to go wrong. Verbal exchanges relating to desired changes in thickness, colour(s) twist levels, fibre type and possible effects are at best abstract and analogue. However, if an accurate CAD system were available for the simulation of yarns, and if both designers and sales staff were able to use it, then the design of new yarns, and the rapid prototyping of samples would be enabled. Imagine a designer being able to simulate a new product on the

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stand at a fair, including the resultant swatch. The manufacturing parameter report would then be sent back to the yarn company's sample development unit and a sample cone would be on the designer's studio table before she/he returns to base. Taking things further, the day may come when a consumer could go into a retail outlet and design the yarn and fabric they want in an intended apparel purchase. The reader may consider this to be pipe dreaming but many technologies that exist today were the dreams of researchers not so long ago. For the final stages to be achieved, the yarn and fabric simulations will have to be virtual and able to be handled. For this to be possible, the yarn and fabric simulations have to be 3D and accurate with regard to mechanical properties as in the case of YarnCAD.

3.7 Conclusion

In recent years, there has been increased interest in the necessity to provide accurate 3D CAD simulation for textiles and apparel; however, real progress on yarn structural modelling has not yet kept pace with this in the commercial sector. Some interesting features have been introduced in the knitting machinery area but a cursory observation of the interface reveals that the input parameters are flawed and insufficient to allow accurate simulation from manufacturing parameters. An interesting website report appeared in 2002 (Adanur *et al*., 2002) which explained that a simulation model of yarn structure was being developed using image recognition and neural networks to focus on the parameters of diameter, hairiness, twist and density. The researchers state that from these simulation models they would be able to recall the yarn either by its image or by its associated structural features. This appears to be database building and is unlikely to produce sufficiently accurate and robust models of yarn structure simulation. The YarnCAD software remains a research project and may only reach the commercial sector if the industry starts to demand the level of sophistication and speed that will be necessary for industrial survival as fast fashion and customisation become expected by the consumer. Recent developments have included the facility to display mixture or melange yarn simulations and consequent improvements to the structural model allowing better fibre definition and hairiness to be incorporated.

3.8 Acknowledgements

The authors wish to acknowledge the contributions made to YarnCAD by many colleagues and ex-colleagues at De Montfort University and colleagues at the University of Leeds. The EPSRC must be thanked for their financial support, without which YarnCAD would not exist. It must be observed that YarnCAD is a copyright trade mark of De Montfort University.

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4

Improving apparel sizing and fit

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4.1 Introduction

Finding a garment that fits properly and looks stylish is a dilemma and frustration to many, especially those who are not the so-called 'average size'; and with variability in size, proportion and shape, consumers, retailers and manufacturers still grapple with issues of garment sizing. This has led to consumer dissatisfaction with sizing. Achievement of garment fit is evasive. From body measurement to purchase, sizing issues pervade the supply-chain processes. Today, many people not only live with the difficulties of finding clothes that fit but also suffer the subsequent confusion about garment sizing. Consider this scenario. A lady goes to the high street in search of a garment for a special function for herself and her three-year-old daughter. She hopes to buy either a skirt or a pair of trousers with an appropriate jacket. While window shopping, her attention is drawn to a skirt from one store and a suitable jacket from another. She remembers that she had once bought a dress, sized 38 and a skirt sized 28 from the first shop. Deciding to go into this shop first, she examines several garments – skirts sized: 8 to 16; S, M and L; and 24 to 30. The jackets are sized: S, M and L; 8 to 16; and 34 to 42. She selects two styles of each and tries them on in the fitting room. Although the first skirt (designated 'size 12') fits at the waist, it is too tight at the hips. The second skirt fits her but in the 'L' designation which replaces her initial choice in 'M'. She goes to the second shop in search of the jacket. She selects one jacket that is labelled 'M' and another, labelled '38'. The first one has sleeves that are too short for her, while the second one fits but in 'size 40'. For her daughter, the lady has to choose between garments with the following designations: S, M, L; 22, 24, 26; heights 92, 98, 104, 110 cm; 3 years, 4 years, 2–3 years and 3–4 years. Faced with this multiplicity of size codes, the selection of correct sizing is daunting. These experiences are not unique to this lady. Many people have had similar experiences at one time or another in our quest for well-fitting clothes. For older women for example, finding clothes that are stylish and fit well and accommodate physiological

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changes is a great challenge. For older people these changes accentuate with time and include: expansion of abdomen, trunk girth and hips, thickened waistlines, decrease in height, rounded backs and lower bust lines (Shim and Bickle, 1993; Goldsberry *et al*., 1996b).

4.2 Key issues affecting apparel sizing and fit

Anthropometric data are the cornerstone of sizing systems and, as such, are considered proprietary and marketing tools for retailers and manufacturers, and are used for size discernment and communication by consumers. Surveys are historical benchmarks for industry standards and, today, management and manipulation of body data are the focus of modern non-contact technologies. From the 1930s, anthropometric surveys have been used to collate data on military and civilian populations of men, women and children. Bye *et al.* (2006) present a detailed evaluation of various methods used: linear (tape measure, callipers); multiple probe (adapted tape measure, anthropometers, somatography, planar, computer integrated apparel manufacture, photography); and body form (draping, casting, scanning). One principal aim has been to generate data for designing garments that provide comfort and appropriate fit (Roebuck, 1995). Anthropometry is the systematic measurement of the human body in order to determine its physical dimensions and the proportion of its parts among different ages and races or groups (Sanders & McCormick, 1993; Roebuck, 1995; Otieno, 1999). Clothing design requires the accurate measurement of the body in order to generate better fitting garments for consumers. Clothing anthropometrics deals with data that are used for clothing sizing and pattern development, size coding by retailers and manufacturers, and communication of sizing information to consumers. At the core of clothing anthropometrics are therefore three key issues: how to measure the body adequately, how to analyse the vast data into efficient size charts and how to use the size charts in marketing in order to create customer satisfaction with clothing. The processes of gathering body measurement data, their critical analysis and logical interpretation into size charts are the first steps towards this goal. The purpose is to achieve the most advantageous match between garments and the needs and inclinations of the wearers. In general, clothing anthropometrics has the following aims.

1. To facilitate the improvement of standards of manufactured clothing, e.g. fit, sizing and performance.
2. To improve the process of making clothes, e.g. lay planning, styling.
3. To facilitate the development of size charts based on scientific evidence, e.g. grading.
4. To develop a better understanding of human factors involved in the development of clothes, especially: high-performance wear, clothes for

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particular groups of people such as children, older people and disabled people; and specialised wear (sportswear, wedding outfits, stage wear, etc.).
5. To enhance consumer satisfaction by developing clothes that fit well, through understanding of underlying factors such as maturity, ageing and posture.
6. To develop a greater understanding of the processes of data management and analysis that lead to the development of patterns.

Despite the above listed intentions, various issues regarding the sizing of garments persist: availability of and variations in body measurement data; variations in practice regarding sizing systems, size codes and ease allowances; meanings and utilisation of body measurement data; and confusion, consumer satisfaction and dissatisfaction with garment fit. These issues are discussed below.

4.2.1 Availability of and variations in body measurement data

Measurement of the human body is an important aspect in attaining and providing adequate fit. Utilisation of appropriate anthropometric data is key in developing effective sizing. Such data are the basis for determining both the size range (smallest to largest) and variation (differences in proportions). To provide valid body measurements for all populations, one would need to do the impossible task of measuring each and every individual. Representative samples have been utilised instead. Surveys are expensive, require specialised expertise and are usually proprietary to the funding agencies. Data that are available in the public domain are usually outdated. Companies have mainly utilised adapted data based on estimations. The lack of relevant, valid and current anthropometric data has resulted in the use of unreliable size charts and systems. Different procedures are used to measure the same variables and this makes it difficult to compare data. In manual surveys, there is variation in how key dimensions are measured and determined. Sizing systems vary according to concept and principles of development. For example, the proportional sizing systems are derived from nineteenth-century tailor's drafting techniques and expertise where the tape measure was the key tool for measurement for custom-made garments. Landmarks and measurements are linked directly to shape and dimensions of garment based on body contours. The assumption that garment making is a craft has contributed to the misconception that anthropometrics is not a scientific process. There is also obscurity and secrecy in how data are analysed, both for manual and scanning procedures.

Traditional tailoring activities have grown from merely draping to include more sophisticated tailored looks (Kidwell and Christman, 1974). The sizing

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of ready-to-wear garments has evolved in a fragmented and competitive environment (Tamburrino, 1992). With the invention of the sewing machine around 1850, faster and more efficient ways of making mass-produced clothes were established and the need for sizing systems with clear communication was felt. Developments in sewing equipment, cutting and distribution, and also mass production methods, have facilitated ready-to-wear products. In the second half of the twentieth century, technological advances focused on new methods of human measurement using contact or non-contact techniques and with the promise to overcome the shortcomings of previous practices. The efficient measurement of the human body is now being viewed as the panacea to the provision of adequate fit and sizing, and also consumer satisfaction with clothing. It is difficult and complex to distinguish what makes good fit. There is no common agreement among designers, patternmakers and consumers regarding how to determine fit. Furthermore, there are no common industry standards on fit and, if there were, there would be variation in application. In theory, standardisation would have been a panacea to solving sizing problems by providing a variety of fittings for any body type. It has been suggested that body size variability may be due to various factors: population mix, biological and social differences between groups – e.g. age, sex, ethnicity, social class and occupation (Gioello and Berke, 1979); changes in nutrition and activity level; changing immigration patterns; population phenomena – e.g. population growth spurts (Goldsberry *et al*., 1996b; Behling, 1999) and the secular trend.

According to Roebuck (1995), surveys are a historical science since people evolve and undergo change. Anthropometric surveys, even if conducted on the same population, for example, can never yield the same data since normal physiological changes (ageing) take place and subjects become unavailable. Surveys are benchmarks against which future data can be pitched. Although the need to measure and quantify the human body was acknowledged as early as the Renaissance, it was not until the 1950s that anthropometry developed as a discipline with codified measurement instruments. Today, a variety of methodologies, procedures and instrumentation using both traditional and modern approaches are available. There have been various surveys in the twentieth century. Before 1937, some small-scale surveys had been conducted in the medical profession (Cooklin, 1991). The first major children's survey was conducted in the USA between 1937 and 1939. The measurements were used for developing uniform grading for children's patterns. Over 147 000 boys and girls (4–17 years old) were measured. The data generated a sizing system based on height and hip girth (O'Brien *et al*., 1941). Measurement procedures, such as land marking, that were developed from this survey have been adopted for subsequent surveys and continue to be used today (Cooklin, 1991). This study is significant as it forms a landmark in the development of sizing systems for children's clothing. As an outcome of the above children's

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survey, the Commercial Standard CS 151 and other standards were developed (Winks, 1997). TS-5184, a Commercial Standard on body measurements for the sizing of children's garments was accepted in 1948. The purpose was to provide standard classifications, size designations for ready-to-wear garments and patterns, landmarks and methods of body measurement.

Surveys are significant because they present records of procedures, methodologies, databases and varying levels of analysis of data. These practices form the basis for many traditional surveys even today and are also the basis for development of new scanning technologies. Surveys also provide records of development in technology and illustrate the efforts by companies to meet industry and consumer needs. For example, today's online shopping requires incorporation of sizing information during the buying process. Virtual fit technology aims to present the most realistic representation of sizing experience in time.

The first published clothing survey, for 100 000 men, was conducted in 1921 in the USA (Winks, 1997). The first major women's clothing survey in the USA was conducted in 1939/1940 with 15 000 women (O'Brien and Shelton, 1941). Data from this survey became the basis for the development of size charts in the USA, Europe and some other parts of the world. This precedent survey provided measurements for improving fit and for developing the Commercial Standard CS 215-58 for pattern development which was later updated in 1968 and then formed voluntary Product Standard PS 42 in 1970. The Swedish Survey of 1957 is significant for the introduction of the centilong system (Morgan, 1973; Cooklin, 1991). The first national women's survey in Britain was conducted in 1957 (Kemsley, 1957). Several children's surveys were sponsored by a consortium of retailers, for example: 1979, 3500 boys aged 5–16 years were measured; 1986, 4500 girls aged 5–16 years were measured; 1987, 6500 babies and infants were measured. This measurement of British boys and girls from birth to 16.9 years formed the foundation of the British Standards for children, Parts 1 and 2 (BSI, 1990). There has also been a survey for the measurement of school children (Department of Education and Science, 1985). A survey of British males generated body measurements in 1980 (WIRA, 1980). Every decade since 1966, there have been national surveys on the measurement of women and girls in Germany (DOB-Verband, 1994). Recently, other studies in the USA have focused on the measurement of the mature population (Goldsberry *et al*., 1996a; Ashdown and O'Connell, 2006).

Anthropometric surveys provide pertinent data that are used for nomenclature and sizing systems. Sizing surveys have been the basis of revision and improvement of existing national systems in several countries. Rodwell (1970) reports on the first systematic inquiry into women's sizing in Holland, 'De Juiste Maat Size System in 1950' which manufacturers rejected, but after 1960 they accepted the centilong system for children's

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clothing. The Dutch children were confirmed to be the same size as the German children.

4.2.2 Meanings and utilisation of body-measurement data

From antiquity, people have been concerned with covering their bodies. It is thought that the first clothes were made out of leaves, skin and tree barks. These were sewn together into a flat piece which was then draped onto the body. While serving the purposes of decoration, protection and modesty (Flugel, 1976), clothes are believed to be as old as man and are central in first social encounters. Clothes are sometimes worn to impress or even determine the way one is perceived, and garment sizing is embedded with symbolic meanings. For example, wearing a smaller size code could imply that one is 'small and dainty' and therefore beautiful. To be as small as a thin catwalk model may be very appealing to one's vanity. Some retailers have utilised this aspect in indicating a smaller size code for a larger fit to meet this psychological need in wearers. In the 1980s, the concept of power dressing emerged; the wearer was perceived to gain a certain positive and powerful image because of the type of clothing they wore. Size and fit are significant aspects because in today's society they are linked to symbolic categorisation of the wearer's body as 'small', 'standard' or 'tall'. Because of the concept of the 'average' size, the wearer is expected to fit into an available size category. This 'average body' fallacy assumes that every person of any size and shape can fit in these sizes. In essence, many people whose body proportions do not fall in these categories have no choices. The main aim of anthropometry is to find an efficient match between the user and the product. In the case of clothing anthropometry, the aim should be to have sufficient sizes that can fit all body sizes and shapes. The approach should be 'This garment will not fit me' instead of 'I cannot fit in this garment' (Pheasant, 1986; Oborne, 1987). Companies have often conducted proprietary surveys to meet their target market needs, and sometimes marketers have manipulated psychological influences (e.g. vanity sizing) and body image aspirations through celebrity endorsement and the portrayal of the ever-elusive and mythical 'average' size as ideal. The recent debate on the use of extremely small models on the catwalk has highlighted the issue of basing garment sizing on unrealistic sizes and its influence on the vulnerable, especially teenagers.

Whether to provide modesty, protection or decoration to the body, one fundamental concern about clothes has been how to assess the size and proportion of the body in order to assign an appropriate size. Covering the human body has proved complicated because of variability in size, proportion and shape. For example, people of the same gender and age may differ in body proportion: tall and slender, tall and plump, short and slender, short and plump. Variations include specific body part shapes: long legs, prominent

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hips, short waist, plump upper or lower torso, or even the whole body (e.g. very tall, very short, very thin, very big). Various sizing systems, e.g. petite, have been developed to meet such needs. The wearer's perception of fit is culturally influenced and therefore there are variations in what is considered to be an acceptable fit. Worldwide, anthropometric surveys have been used to collect vast amounts of useful data. These are used for the purposes of attaining precision of size and fit in garments for men, women and children. Using such data, garment size charts are determined especially for mass production. However, there are still populations that have not been measured and for whom only adapted size charts are utilised. With the globalisation of the clothing industry, local sizing strategies are necessary. Regional sizing systems have been initiated, for example European sizing co-operation efforts resulted in the development of the European Standards EN 3402 – Parts 1 to 4 that have been adopted across Europe (BSI – 2001, 2002, 2003).

4.2.3 Variations in practice regarding sizing systems, size codes and ease allowances

Although the usefulness of anthropometric data in developing effective sizing systems has been recognised for many years, its utilisation has neither been uniform nor a panacea for all problems. Traditional approaches to anthropometry have prescribed methods and instruments for measuring linear heights, depths and widths, sometimes with calibration. Usually landmarks are identified using bone structures beneath the skin which are then marked on the body. Although landmarks show the beginning and end of a dimension, their determination and measurement can be inaccurate and variable, resulting in invalid and unreliable data. To avoid intra- and inter-measurer errors, training of personnel is necessary. Sampling procedures have to consider population representation, especially where size charts are a required outcome. Analysis and interpretation of data require statistical knowledge and its application to clothing design issues. Because surveys are time consuming and expensive, availability of reliable data that are current is rare; and when available they are proprietary and not freely available in the public domain. This has sometimes resulted in the use of outdated sizing systems.

Fitting trials have been used to establish the suitability of products for the user population (Pheasant, 1986). These are experimental studies in which the designer systematically explores user preferences by means of adjustable mock-up of the product using dummies, live models or, more recently, virtual three-dimensional models. Accuracy of fit is a goal that many current technologies stress (DOB-Verband, 1994; Roebuck, 1995). As opposed to custom-made garments where various dimensions of the body are directly transposed to the relative parts of the pattern resulting in the finished garment fitting the body, the ready-to-wear garments are made to fit an imaginary

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average size or categories of people whose measurements and figure characteristics are not known before manufacturing begins (Carr and Pomeroy, 1992). Since the advent of mass production, nomenclature – i.e. what to call a size – has been a problem and this persists today. Although communication of fit is important in the clothing industry, confusion exists and there is non-uniformity of symbols or codes used for size designation. With a lack of industry standards on fit, there has been size coding variation within and between retailers and manufacturers, with sizing sometimes being arbitrary. For example, some numerical sizes do not correlate to any body measurements and some retailers have utilised vanity sizing. Garments are labelled variously and sometimes inconsistently with different codes: numerical symbols, e.g. 12, 14, 16 or 1, 2, 3, 4 or 34, 36, 38; control body measurement, e.g. To fit chest 32, hip 38, neck 38.5 cm; finished garment measurement, e.g. inside leg 31; height, e.g. To fit height 92 cm; figure type, consisting of XXS, XS, S, M, L, XL, XXL or Short, Medium, Tall; age and weight, e.g. Age 2 years or Age 2–3 years; 7 lb. In the USA, children's sizing utilises odd numbers 3–13 and Misses sizes have 4–20 (Tamburrino, 1992). In Germany, the codes for girls' size ranges are SS for extra slim, S for slim, N for normal and EW for chubby (Cooklin, 1991; DOB-Verband, 1993). In the UK, children's size codes utilise height and age. In practice, actual garment sizes differ owing to manufacturers' preferences depending on style, and size codes are variously based on numbers, figure type and key or control dimensions.

Before making garments from the size charts, ease allowances are added to certain dimensions. These allowances vary between manufacturers who make similar garments and this is due to the fact that manufacturers have freedom in deciding these ease allowances. Intervals are usually selected for grading and these vary between manufacturers (Kemsley, 1957, BSI, 1990; Workman, 1991). Proper fit of apparel depends on the relationship between the size of the garment and that of the wearer, and this value is critical in protective clothing. Consumers have varying preferences regarding fit, style and design.

4.2.4 Confusion, consumer satisfaction and dissatisfaction with garment fit

Confusion exists about garment sizing. There is variation within the same retailer's products and also between retailers. There is further variation between different countries. The history of children's clothing in Europe illustrates the confusion that has existed across the industry. Until the 1950s, the nomenclature and sizing systems for children's clothing in Europe produced confusion to manufacturers, retailers and consumers (Rodwell, 1970; Guppy, 1978; Cooklin, 1991). Existing size charts were based on the data collected in the USA in the 1930s, nomenclature presented a variety of codes based on

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age, girths and lengths, and there were different intervals for the manufacturers. In 1982, Aldrich (1985) measured 1783 boys and girls aged 2–14 years in the UK and developed four size charts for girls and boys based on the centilong system. Before Aldrich's work, there were the size charts suggested by the British Standards Institute (BSI) after the conference on sizing of children's clothing in 1953, but these had been disputed and disregarded by manufacturers (Guppy, 1978). In 1982, the BSI published their specification for the Size Designation of Children's and Infants Wear BS 3728, this being an update of an earlier version which was first published in 1970 and which was based on the American survey of 1937–1939 (Guppy, 1978). In 1984, a survey of school children was instituted by the Clothing and Allied Products Industry Training Board in Leeds. The main objectives were to prepare size charts for 'the best fit' (James and Stone, 1984, p. 1). Regular size chart revisions have been recommended as a way of keeping track of the continually changing characteristics of the population (Brunn, 1983). Germany has one of the most unified sizing systems in Europe. Research has been partially funded by the government and is accepted by retailers and manufacturers. The first significant survey was in 1961/62; subsequent surveys were conducted in 1970, 1981/82 and 1993. There have been 10-yearly successive revisions (DOB-Verband, 1994, p. 4). Following the success of women's sizing based on the 1961/62 initiatives, a survey of 4400 children followed. Based on the centilong system, which was being practiced then, sizes were divided according to heights of 92 to 170 cm with a uniform size interval of 6 cm. Manufacturers accepted that system which then formed children's size charts in 1966.

Recently, there has been great interest in consumer satisfaction and dissatisfaction with garment sizing. Consumer satisfaction theories are based on analysing discrepancies between expectations and reality, and evaluation of those expectations (Churchill and Suprenant, 1982; Woodruff *et al*., 1991; Erevelles and Leavitt, 1992). Evaluation of consumer satisfaction or dissatisfaction based on products or services provides important feedback to retailers and manufacturers (Stanforth and Lennon, 1998). Comparison of such elements to expected norms is thought to lead to confirmation or disconfirmation of satisfaction. In the clothing sector, customer satisfaction may lead to store patronage (Bennet, 1990) and social and hedonic experiences (Stanforth and Lennon, 1998). Clothing is linked to how consumers view themselves for example, as part of the extended self (Belk, 1988), even as a second skin (Horn, 1975) and well-fitting clothes are considered vital for the individual's psychological and social well-being (Smathers and Horridge, 1978). Workman and Johnson (1989) found that clothing plays a significant role in social interaction, personal acceptance and perceived sociability. Clothing purchasing and satisfaction with the product is therefore important. Several studies have focused on the problems that cause dissatisfaction with

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clothing among older women (for example, LaBat and Delong, 1990; Shim and Bickle, 1993; Goldsberry *et al*., 1996a; Otieno *et al*., 2005). The most common complaints about garment sizing are poor fit, incomprehensible codes and sizes, confusing coding information, inconsistency between brands and lack of half or transitional sizes. Consumers expect adequate, meaningful and informative coding with consistency within and between brands, knowledgeable salespersons and post-purchase care (Otieno, 1999). Failure to meet these expectations has led to consumer dissatisfaction with garment sizing. Evaluation and achievement of garment fit is evasive. From body measurement to purchase, sizing issues pervade the supply chain processes.

4.3 Importance and development of size charts

The processes of size chart development are tedious and complex. Although size charts were seen as a panacea to adequate garment sizing, in practice their development has led to other problems, especially for consumers. There is variation within and between companies and countries. National and international standards exist but often provide varying information. Various methods are used in developing size charts. A size chart is an artificial dividing of a range of measurements that designate body size (Kunick, 1984; Beazley, 1999). Garment sizing refers to the standardised dimensions of garments leading to categories. These categories enable customers to recognise garments that give them reasonable fit and also for retailers to arrange stock. Size charts have to be concise, economical in number, consistent and simple. The number of size charts within a range is aimed at providing convenience for wholesale production and also satisfying customers' requirements. The objective is to fit the maximum number of people within the minimum number of sizes. Beazley (1997, p. 15) concurs with Kunick (1984) that manufacturers and retailers want charts that are concise, economical in number, have consistent intervals between sizes and are simple to read. Size charts have been used to produce size labels which are tools for assisting customers in choosing apparel that properly fits their bodies (Yoon and Jasper, 1996). La Bat (1987) found that size-labelling systems were insufficient in describing women's garment sizes and consumers had difficulty in finding well-fitting garments.

4.3.1 Importance of size charts

Size charts are important in the clothing industry. They are used for standardisation, labelling of garments, stock management and size identification by consumers; they provide proprietary information for retailers and manufacturers; they are used to create consumer satisfaction and as a marketing tool and to create niches. These factors are related to key dimensions, size

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codes, size ranges, grading increments, allowances and international standardisation. For clothing purposes, size charts aid in classifying human physique which presents in varying shapes and sizes. According to Croney (1980), small differences in body proportion, which are almost impossible to detect at birth, are continuously multiplied throughout physical development, presenting as individual morphogenotypes. Since the clothing industry is concerned with mass production of well-fitting clothes for customers with diverse sizes, the need for grading systems to cater for such variation is necessary; the 'starting point for developing a grading system is a size chart' (Cooklin, 1991, p. 8). The functional design of ready-to-wear clothing presents complex anthropometric problems. The clothing designer seeks to provide an acceptable degree of fit with respect to a number of correlated bodily dimensions, minimise the extent to which the garment hampers the movement of the wearer and also provide sizes that can fit a maximum number of people using the minimum number of sizes (Pheasant, 1986). Revision of size charts could reduce garment alteration costs and according to Workman (1991), sizing is a form of competition; a sizing tool. Companies may use sizing to attract customers, create and maintain an identity, encourage patronage, and reduce returns due to poor fit.

There are two types of size charts: body measurement and finished garment (Beazley and Bond, 2003). Body measurement charts consist of size ranges for children, men and women, and are useful for designers, patternmakers and graders (Pheasant, 1984). Finished garment size charts are made up of the body measurements and extra measurements for tolerances and ease allowances. Tolerances and ease allowances vary according to design and fabric and are used for garment inspection and specification. Ease allowance is an extra measurement added to the body measurement for movement and expansion. This is needed for constructing finished garments. The amount varies according to both wearer ease allowance (function or end-use of the garment; type of fabric, e.g. woven or knitted) and the design ease allowance that should accommodate style or fashion. Size charts also contain control measurements or key dimensions. These are usually body girth (chest, bust, waist, hip, neck) or length measurements (height, outside leg, inside leg), or even other measurements (weight, age). The other body measurements are related proportionally to these measurements. A sizing system contains a set of sizes generated from common assumptions and methods of development. Because of variation in nomenclature, different systems are in place, e.g. one-size, SML, numerical (e.g. size 6, 42). Proportional sizing systems that are based on ninteenth-century tailor's drafting techniques are the most common. New technologies for sewing, mass cutting, distribution and production are used today and these provide competitiveness.

Ascertaining a customer's size is difficult and is usually based on body measurements. Very few people are of identical body measurement. The

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lengths, girths, posture, contour and proportional variables all have to be taken into account. Measuring techniques rely on the trained skill of the measurer; some parts of the body are difficult to measure accurately, e.g. neck, armhole and crutch. Current scanning technology aims to overcome many shortcomings of manual measurement approaches; the technology continues to be evaluated and is gaining usability and accessibility in the clothing industry. There are various sources of information on size charts: anthropometric surveys, current published size charts, company size charts, company surveys, literature on design and pattern construction, and workroom stands.

4.3.2 Development of size charts

Although the development of size charts was seen as a panacea to adequate garment sizing and coding, in practice it has led to other problems, especially for consumers. A size label is supposed to be a tool for assisting consumers to select garments that fit them properly. Because of the multiplicity of size codes, consumers are sometimes confused and unable to choose appropriate size. In 1969, the International Organization for Standardization (ISO) launched the development of a revised size designation system. Since the 1970s, many countries have revised their size labelling systems so as to be in line with the ISO system. Size categories are the various groupings of sizes as they would be presented in a retail situation. Thus, the sizing system most commonly used for ready-to-wear makes use of a base size, often standardised to a fit model, and a set of sizes proportionately graded from this size. Examples of size categories include average, misses, petite and plus sizes. To be of practical use, anthropometric data must satisfy the commercial needs of the apparel industry: they must be current, reflect the dimensional distribution of the population and satisfy the technical requirements of the manufacturers (Tamburrino, 1992; Beazley, 1998).

The development of size charts can be done through manual steps using statistical calculations or computerised mathematical formulae. A spectrum of techniques exist for the analysis of data. Quantitative data have been analysed according to pre-determined criteria such as age, height and girth measurements, and summarised using percentiles, means and standard deviations. Correlation and residual analyses have been used to establish size charts (e.g. O'Brien and Shelton, 1941; Kemsley, 1957; DOB-Verband, 1994; Roebuck, 1995; Yoon and Jasper, 1996; Beasley 1997; Otieno, 1999). One setback is that very few analyses are evaluated for validity. Whatever the process, various steps are utilized (Pheasant, 1986; Cooklin, 1991; Otieno, 1999; Beazley and Bond, 2003):

1. Obtain body measurements that generate reliable and valid data.
2. Select control measurements that are relevant to the fit of the garment.

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3. Establish relationships between measurements based on correlations.
4. Determine key dimensions, e.g. the role of height and circumferences.
5. Demarcate the upper and lower limits (fit proportions) of each size.
6. Discern grading increments and allowances (ease + design).
7. Select size codes and size ranges.
8. Test fit and confirm the size charts.

Carr and Pomeroy (1992, p. 51) describe the processes involved in creating a satisfactory size and design in a garment:

> Design of a garment involves the cutting of not one but a range of sizes. To satisfy the requirements of a range of sizes the design process must have an attitude toward a national system of size coding and must decide what body measurements in its garments will be represented by coding, what conditions to make for body measurements for ease and comfort in wear and what allowances to make for different styling features.

4.4 Application of technological advancements

In the twentieth century, technological advances have focused on the new scanning methods. Efficient measurement using scanning technology is now viewed as the solution to the provision of adequate fit and sizing which may lead to consumer satisfaction in made-to-measure and mass-customised environments. New methods using virtual try-on are also utilised. Today, non-contact approaches are utilised worldwide, e.g. national surveys at the beginning of the twenty-first century such as SizeUK, SizeUSA, and SizeChina have used such technology. Current areas of research include acquisition of anthropometric data for various populations, comparison and new methods of analysis, establishment of size charts and sizing systems, and development of standards for different countries.

The focus of new body-scanning technology has been to overcome the shortcomings of manual measurement in order to improve validity and reliability. The main advantages have been the automation of data collection, storage and analysis to enable custom-fit and mass customisation of garments, use of pattern-generating computer-aided design and manufacture (CAD-CAM), and provision of online assessment of fit before purchase. However, scanning technology is still costly. New technology also allows efficient distribution, consideration for the wearer's functional needs, improved stock management and flexible production methods. Manual surveys have used approaches that utilised mainly contact instruments for anthropometric surveys. In such surveys, the international standard ISO 8559 (ISO, 1989) has been the main reference for definitions and locations of body measurement and guidance on how to conduct surveys and create patterns. The character of surveys is usually determined by the objectives, sample, funding and technology.

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Data collection procedures involve setting up of measurement centres or provision of mobile measurement. Ethical and legal issues have to be considered by researchers. Training is usually centred on having all measurers master the techniques for consistency. For evaluation of fit, live and computer models and dummies are utilised in fit and comfort trials. New methods using virtual try-on are also utilised. In traditional manual methods, recording sheets are normally prepared before the exercise. Because body measurements are taken, subjects are normally dressed in the minimum of clothing (Kemsley, 1957; Pheasant, 1986; ISO, 1989; Cooklin, 1991, p. 7) or in specially prepared test garments such as leotards which allow for the landmarks to be located on the body. Some of the above-named practices have been overcome by the use of new scanning technology which offers speed, accuracy and efficiency. Measurers need to be trained to be familiar with the techniques.

Researchers are always faced with the issue of determining what to measure and how to define these dimensions. Measuring the body for clothing purposes is complex. Although the body presents in a three-dimensional form, measurement procedures have in the past been two-dimensional. Subsequent two-dimensional patterns have been presented as flat. This is, however, changing with the new computer-based technologies. Also certain parts of the body are difficult to measure adequately; for example, the crotch, a critical dimension in the development of trouser blocks, is difficult to measure. In all surveys, the vertical, horizontal and girth measurements, age and demographic information are usually recorded. Postures have to be included in the measurements, for example standing and sitting upright. Before commencing an anthropometric survey, it is important to determine the number and types of dimensions to be measured. This usually depends on the objectives of the study, the use to which the data will be put – for example creation of size charts, type of size charts, subsequent analyses – and the ultimate user. Survey reports usually list the actual and derived dimensions, nomenclature and measurement methods that were used (e.g., BSI, 1990; DOB-Verband, 1994; Beazley, 1997).

Surveys are determined by the available equipment and various other factors such as time, age and disability. Since the 1930s, the identification of measuring positions, dimensions and landmarks or anatomical points has been central to the practice of clothing anthropometry (O'Brien and Shelton, 1941; O'Brien *et al*., 1941; Kemsley, 1957; Aldrich, 1985; BSI, 1990; DOB-Verband, 1994). 'New technologies have such built-in capabilities to address specific concerns. For example, computer modelling includes dimensions to locate joint centres of rotation, interjoint link surfaces and offsets in relation to 3D coordinate systems' (Roebuck, 1995, p. 9). In describing measuring positions, descriptive or other terms that illustrate the distance between anatomical points are used. Roebuck (1995, p. 12) concedes that there is a need for integration of traditional and new technologies. Landmarks or

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anatomical points are marks made on the subject's body to identify the beginning and end of a measurement during the traditional contact surveys. Several anatomical marks are usually identified on the body. These are normally bony structures at different locations on the body. Some of the new scanning technologies claim to identify landmarks automatically; however, there is need for uniformity.

The clothing industry has transformed during the twentieth century with the use of scanning technology in body measurement and the subsequent utilisation of such data. This may have great implications for marketing approaches. More recently, information technology has been cited as having the potential to revolutionise the clothing industry: it offers working practices where manufacturers can provide highly competitive, flexible and fast service; it offers fast communication between retailers and designers; it feeds the manufacturing process with designs that have immediate market and offers a quick-response culture where stocks are kept to a minimum and buying trends can be serviced quickly and efficiently. This implies that the clothing industry is of great interest to the computing and communication suppliers. The current uses of information technology in the industry have been in CAD-CAM, and electronic point of sale (EPOS) processes (Beazley, 1997; Istook and Hwang, 2001), computerised made-to-measure technologies and development of methodologies for measurement of body size and shape (Roebuck, 1995).

Although the current usage pivots around designing and retail management, the scope of future research is set to revolutionise the industry, including the provision of virtual fashion shows and the viability of the Internet as a forum for fashion retail marketing. While the Internet does present marketing opportunities, the majority using it were companies that viewed it as a means of gaining global presence.

There are governments, universities, research institutes and corporations worldwide where non-contact measuring systems are being developed and utilised in research. In Europe, Italy-based CAD-Modelling S.r.l. and Telmat Informatique, a French manufacturer, produced an electronic measuring device MIDAScan and the MIDABase data management system. In the UK, Nottingham Trent University conducts research in the area of anthropometrics. The HUMAG Research Group at Loughborough University, which was funded by the Application of Computers to Manufacturing Engineering (a consortium of industrialists) and clothing companies focused on female body figurations to create state-of-the-art mannequins, using the Loughborough Anthropometric Shadow Scanner (LASS) (Anon., 1994; Jones *et al.*, 1995). In the USA, three-dimensional scanning technology was developed by the Textile/Clothing Technology Corp. ($[TC]^2$) and Clemson Apparel Research (CAR) (Anon., 1994; Staples *et al.*, 1994) and which Abend (1992) projected would

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revolutionise the time cycle in the apparel industry. In Japan, Bunka Women's University collaborates with NEC Corporation (Liao, 1997).

4.5 Application

Sizing information can be utilised through national and international standards and company specifications for selected targets. Today, retailers have to meet targetted psychological needs, e.g. those related to vanity sizing and body cathexis. Although new technology promises better validity and reliability over traditional manual methods, issues of integrity of data, compatibility between software and inhibitive costs still persist. Objective measurement of fit is yet to be fully realised. The individual wearer has to confirm acceptable fit in the final instance. Because fit is a complex issue, the views of the designer, the patternmaker and, ultimately, the consumer regarding fit may vary. The conventional methods of testing fit using live models, dummies, or more recently three-dimensional virtual models, all have shortcomings. Models represent only one shape and size as opposed to the real world where people of the same size may present varying fit preferences and postures. More recently, the use of very thin models has been a contentious issue as they are viewed as poor role models (unreal body size) for young girls who may take desperate measures to become as thin as these models. In addition, their sizes are unlike 'normal' (larger) women. The use of dummies presents unrealistic evaluations of fit since the issues of functionality and posture cannot be evaluated. The utilisation of online fit-determination technologies requires the interactiveness that will present an exciting and aesthetically pleasing interface for the consumer. However, new technology offers improved body measurement, analysis of data, manipulation of pattern data in three-dimensional formats, management of data and products, and purchase and post-purchase processes. Made-to-measure and mass customisation are possible with the new technology. Online fit technology offers virtual design, fitting and visualisation of products before purchase and consumer participation in the design process. Simulation of fit, appearance and drape, and appreciation of fit are possible with the animation technology.

Guppy (1978) narrates the history of the confusion that existed about children's clothing in the UK, citing, in 1937, the trade journal *The Children's Outfitter*, which coordinated a retailers' meeting on the issue of sizing. In 1953, the BSI staged the first conference on garment sizing at which all sections of the trade were represented. However, at national and international levels, substantial differences exist between the measurement combinations used for each size by individual manufacturers. Some countries, such as the UK and Germany, have laid down standards for the sizing of children's clothing but these are not mandatory (BSI, 1990). Before 1992, ISO prepared a sizing system to form the basis for a single European sizing called

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'mondoform'. Based on two factors, height and body type, it was hoped that this system could help to alleviate the confusion about sizing as well as provide a standard method of size designation. The alternatives were pictorial presentations. It was hoped that each country would use the same system but with body types and control measurements from the relevant population. Anthropometric measurements are used in matching the dimensions of garments to the wearer. Pheasant (1984, p. 3) suggests that a single critical dimension or a combination of several dimensions may be used. Such information is useful in matching the product to the population of users with a variety of sizes and shapes, and providing a range of correlated measurements. Studies have provided information aimed at improving the fit of garments or overhauling practices that were based on out-dated data (Kemsley, 1957; BSI, 1990; DOB-Verband, 1994). Based on survey data, national and international standards have been developed and these have subsequently been used to strengthen practices in clothing anthropometry. The ISO has various standards related to body measurement and garment sizing. These include ISO 3635, 3636, 3637, 4415, 3638, 4416, 4417, 4418, 8559, 7250, 2816, 3355, 3836 and 3844. ISO 8559: 1989 on garment construction and anthropometric surveys, and ISO 3638-1977 and ISO 3635 on definitions and body measurement procedure, are recognized worldwide. Examples of British national standards include British Standard BS 3666, BS 3728, BS 5426, BS 5511, BS 5592, BS 6185, BS 6308, BS 4981, BS 7231 and BS EN 3402 parts 1–4. Other countries worldwide have standards related to body measurement and clothing sizing and these can be obtained from country websites, for example: Hungarian MSZ 6100/1-86; Japanese Industrial Standard JIS L 0103-1990; Korean Standard KS K 0051-1990; Kenyan Standards KS 08-412, KS 08-410 and KS 08-41. The American Society for Testing and Materials (ASTM) Institute for Standards Research presents various standards related to sizing including ASTM D 13.55, 5585-95, D6829 and D5586.

4.6 Future trends

Future sizing provision will accommodate the utilisation of new technology and selective manual techniques into made-to-measure, virtual fit, online shopping and lifestyle needs and wants of consumers in this millennium. The non-contact measuring approach, based on the just-in-time strategy for manufacturing for the clothing industry, originated in the USA (Pargas *et al.*, 1997). Other advantages were projected to include time saving, identification of individual morphologies, reduction of the garment rate of return, stock management and ultimately improvement of garment fit and customer satisfaction (Anon., 1993). Other advanced technology techniques include the use of lasers and video devices which demand technical know-how

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(Roebuck, 1995, p. 5). Hailing the use of electronic modelling technologies, Roebuck suggests that CAD can perform three-dimensional visualisation and statistical manipulation of body sizing and shaping, a strategy utilised by Liao (1997) while developing made-to-measure patterns for ladies garments. One disadvantage with the new technologies is that they are expensive and, as yet, methods of analysing these current technologies are inconclusive (Roebuck, 1995, p. 12) and therefore 'there remains a need for the integration of traditional and new technology in the context of anthropometrics and for establishing of a permanent committee to oversee and suggest new standards as technology changes rapidly in the electronic age'. Today, the instruments and techniques used are increasingly sophisticated and precise. New scanning technologies have promised many advantages over the traditional methods: They reduce guesswork about body surface, allow CAD and rapid prototyping, alleviate dependency of the measurements on the subject's positioning when measured, provide infinite variety of measurements, can measure subjects when clothed, they use realistic postures and are non-contact and unintrusive. Made-to-measure, where individual body measurements generate customised patterns and garments, has been hailed as the evolution from mass production to mass customisation. There are new tools and technology that facilitate the automated made-to-measure market.

4.7 Sources of further information and advice

- British Standards Institute: www.bsi-global.com
- American Society for Testing and Materials: www.astm.com
- German standards: www.dobverband.com
- International Organization for standardization (150): www.iso.org
- Australian standards: www.standards.org.au
- South African standards: www.sabs.co.za
- International surveys:
  - SizeUSA: www.sizeusa.com
  - SizeChina: www.sizechina.com

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5

Three-dimensional body scanning to improve fit

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5.1 Introduction

A very important first step in creating garments that fit the consumer is determining the correct sizing for each garment. Historically, tailors and fashion designers have used measuring tapes to obtain the physical measurements of the bodies they created clothing for. This method has been time consuming, invasive, and often inaccurate, based on who took the measurements and how they took them. Until just recently, only tailors and couture houses actually still used real body measurements to create or alter the clothing they produced. Mass production strategies of the past 60 years encouraged the move from garments made-to-fit to garments made-to-size. Unfortunately, the sizing systems that have developed through the years are neither standardized nor related to the average human's body measurements. (Istook and Hwang, 2001; Newcomb and Istook, 2006)

While 'fit' might involve both a subjective evaluation (tight versus loose) and an objective evaluation (4 cm bigger than the bust measure) of a garment, underneath it all is the need for a comprehensive set of measurements for each interested consumer. Regardless of the consumer's perceptions of 'fit', it is impossible to meet their requirements for 'good fit' without a set of accurate measurements to begin with. To obtain precise physical measurements, a basic knowledge and set of skills are required that are not often found in the average salesperson at a retail clothing outlet. Beyond that, most consumers do not have the time and would be unwilling to submit to the intrusion of being measured. A 1988 anthropometric survey of US Army personnel required 4 h to physically landmark, measure, and record the data of one subject (Paquette, 1996). How many people do you know that would be willing to sacrifice that kind of time to find a garment, any garment, that fits well?

Three-dimensional (3D) body-scanning technologies were developed to aid the apparel industry in finding solutions to some of these significant consumer fit issues. They may be able to benefit the industry for many reasons.

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1. Body scanners can obtain an unlimited number of linear and non-linear measurements of human bodies (in addition to other objects) in a matter of seconds.
2. Because an image of the body is captured during the scanning process, the location and description of the measurements can be altered at any time and as often as needed.
3. The measurements obtained have the potential of being more precise and reproducible than measurements obtained through the physical measurement process.
4. With the availability of the original scanned image of the body, the possibility exists for garments to be created three-dimensionally specifically for that body.
5. The 3D image of the body can enable fit analysis before a garment is ever actually made.
6. Scanning technology allows measurements to be obtained in a digital format that can integrate automatically into apparel computer-aided design (CAD) systems without the human intervention that takes additional time and can introduce error. This will facilitate mass customization of garments by the apparel industry.

5.2 Types of body scanning technology

Three-dimensional body scanners capture the outside surface of the human body by using either an optical technique in combination with light-sensitive devices, or low-power radio signals (millimeter wave or microwave) (Intellifit, 2007). Generally, the scan can be taken without physical contact with the body. Body-scanning systems consist of one or more light sources, one or more vision or capturing devices, software, a computer system, and a monitor screen in order to visualize the data capture process. The primary types of body-scanning systems are laser, light and microwave. Surface tracing systems also exist; however, these are not currently used for capturing the shape of human bodies. Table 5.1 lists scanners by the type of technology used to capture the image.

In the optical systems, an object is first illuminated by the mechanical motion of one or more light sources, either white, infrared, or laser. Second, charged-coupled device (CCD) cameras detect and scan the reflected patterns off the object. Third, the displacement of the structured light pattern is used to calculate the distance from the subject to the CCD camera. Finally, software inverts the distance data to produce a 3D representation. According to Kaufmann (1997), during the software inversion, a certain amount of redundancy is important to overcome shadowing of arms and ears.

In the radio- (or micro-) wave system, very low level sound waves are bounced off an object to identify the object's location in space. The data

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Table 5.1 Three-dimensional scanning systems by type

Light-based systems		Laser-based systems		Sound wave/other systems	
Company	Product	Company	Product	Company	Product
Hamamatsu	Body Line Scanner C9036-02	Cyberware	WBX, WB4, WB4 Color	Intellifit	Intellifit
Loughborough University	LASS	Hamano	Voxelan		
Puls Scanning System GmbH	Puls Scanning System	Human Solutions	Vitus LC, vitus XXL		
[TC]^2	2T4, 3T6, NX12, NX16	Polhemus	FastSCAN		
TELMAT Industrie	SYMCAD 3D Virtual model, SYMCAD Optifit	Vitronic	Vitus Pro, Vitus Smart, Vitus Ahead, Pedus		
Turing	Turing C3D				
Wicks and Wilson Limited	TriForm				

Note: three-dimensional scanning systems not potentially used for apparel applications were excluded from this table.

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collected become an electronic cloud of points that emulates the shape of the object. Software allows the extraction of measurements from the point cloud of the object.

5.3 Light-based systems

5.3.1 Shadow scanning

Loughborough Anthropometric Shadow Scanner

One of the earliest 3D body-scanning systems was a shadow scanning method developed by Loughborough University in the UK. The Loughborough Anthropometric Shadow Scanner (LASS) differs from other structured lighting approaches in that it requires only a camera, a desk-lamp, a pencil, and a board with grids. The camera faces the scene illuminated by a halogen desk-lamp. The camera captures images as an operator moves the light so that the shadow scans the entire scene. This constitutes the input data to the 3D reconstruction system (Bouguet and Perona, 2000).

The LASS is an automated, computerized 3D measurement system based on triangulation. The subject stands on a rotating platform and is turned 360° in measured angular increments. A slit of light is projected onto the body in a vertical plane that passes through the center of the rotation. A column of cameras is used to read the image of projected light. From the camera image of the edge of the light slit, the height (h) and horizontal radii (r) of the body at the vertical plane can be easily calculated. The measured data are 3D surface coordinates of a body in cylinder coordinate form. The resolutions of measurements in the vertical and the radial directions are 1 and 1.6 mm, respectively, according to the camera resolution (Jones *et al.*, 1995).

Telmat

SYMCAD Optifit is Telmat's 3D body-scanning system, which was originally developed in the framework of a partnership with the French Navy (Istook and Hwang, 2001). The SYMCAD SizeMatch system has a size-selection table that was originally based on ISO 8559 and allows coordination of integrated garment ensembles or packages. The resulting measurement data can be integrated into the major apparel CAD systems for use in made-to-measure systems.

TELMAT acquires pieces of information instantaneously (Telmat, 2007a). After computational calculations are made on the formed scanned image, the system is able to generate a set number of precise body measurements. The SYMCAD OptiFit Pro is a totally configurable version, allowing an increased level of accuracy, coverage, and measurement output (Telmat, 2007b). The

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SYMCAD systems are not affected by body movements since the scans are acquired instantaneously. The colors of scan gear and skin also have no impact on scan acquisition, since data are acquired using shadow scanning techniques.

5.3.2 White light scanning systems

Textile/Clothing Technology Corporation ([TC]^2)

[TC]^2 uses a phase-measuring profilometry (PMP) technique that was developed for commercialization. PMP is similar to Moiré light projection techniques (Arai *et al*., 1991), but differs from Moiré data-capture approaches in that it employs a phase-stepping technique. This method is thought to improve overall image resolution (Paquette, 1996).

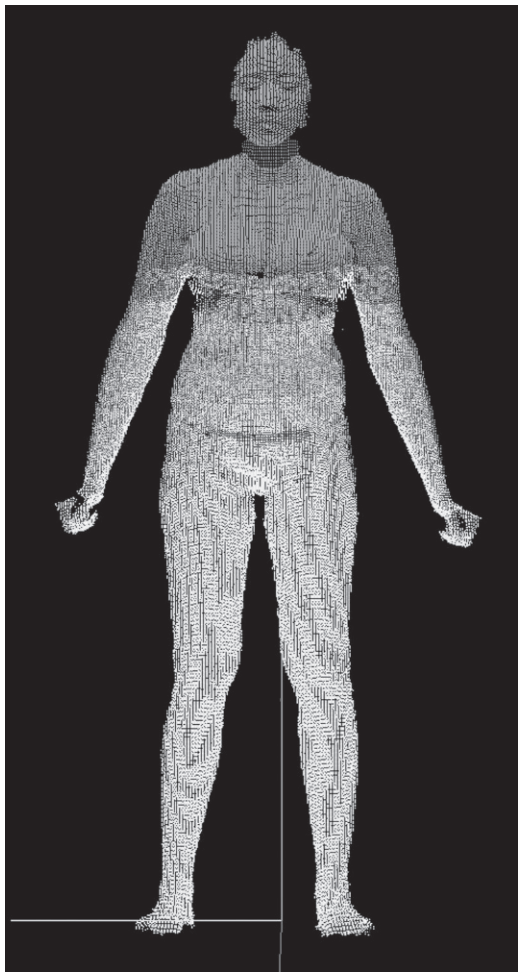
The PMP technique uses a white light source to project a contour pattern on the surface of an object (Istook and Hwang, 2001). A CCD camera linked to a computer detects the resulting deformed light strip. The superimposed projection grating lines interact with a reference grating, forming the fringes. As irregularities in the shape of the target object distort the projected grating, fringe patterns result. The PMP method involves shifting the grating pre-set distances in the direction of the varying phase and capturing images at each position. In the most recent system ([TC]^2, 2007), the NX16, a total of two images are taken with each of the 32 sensors, each with a different exposure level. Using the captured images, the phase of each pixel can be determined. The phase is then used to calculate the 3D data points.

The intermediate output of the PMP process is a data cloud of points for each of the views. The individual views are combined by the exact orientation of each view with respect to one another. Scanning a calibration object of known size and orientation is an essential step in deriving this orientation. This is known as system calibration ([TC]^2, 2000). The points that result from the data set are the raw calculated points without any smoothing or other post-processing (Fig. 5.1). In order for measurements to be extracted, the data must be further processed by filtering, smoothing, filling, and compressing (Fig. 5.2). The PMP method enables faster data acquisition than laser scanning or shadow scanning, but is unable to provide color information.

Wicks and Wilson Limited

TriForm is a non-contact 3D-image capture system from Wicks and Wilson Limited in the United Kingdom. White light in a series of striped patterns (a variation of the Moiré fringe technique) are projected onto a person who should ideally be wearing light, form-fitting clothing or underwear (Wicks

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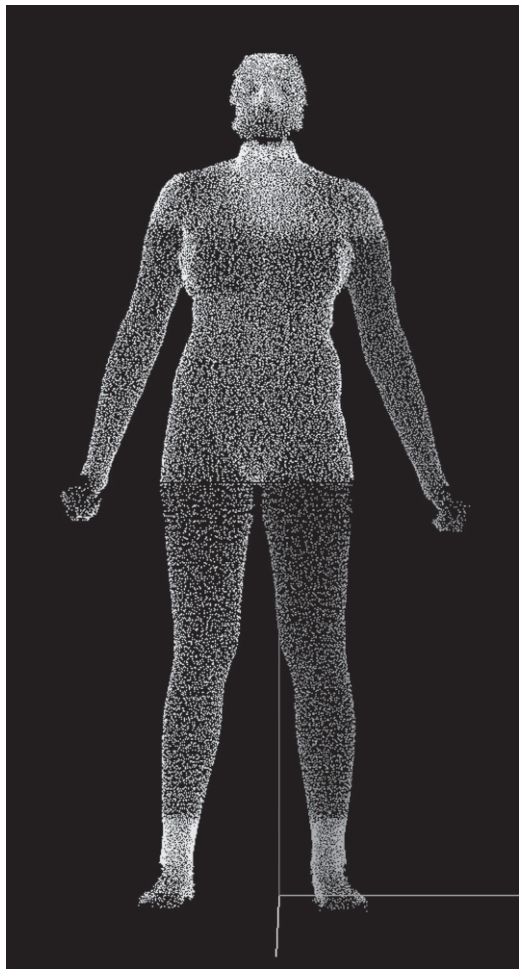


5.1 Intermediate point cloud output of $[TC]^2$ data.

and Wilson Limited, 2007). The 3D shape is a colored point cloud on the monitor screen that looks similar to a photograph of the subject.

TriForm was tested in a large garment-sizing survey in the United Kingdom organized for Marks and Spencer. They anticipate that it will increase sales, enable virtual displays at point of sale and in catalogues, and can provide a wider range of garments than a normal storeroom. Virtual garment try-on will also be possible in the future. This technology is expected to have application in e-commerce for Internet shopping, in the medical field to assist surgeons in case management and planning, in multimedia and image manipulation, and in garment sizing for the apparel industry.

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5.2 Reduced body data output of $[TC]^2$ scan.

5.3.3 Light-emitting diodes

Hamamatsu

The Hamamatsu Body Line (BL) scanning system uses near-infrared light-emitting diodes (LEDs) to obtain scan data. The system was developed to extract 3D body data using fewer body landmarks and having less missing data than other previously developed systems. Light is pulsed through a projection lens onto the subject. Near-infrared light is reflected from the subject being scanned and is collected by the detector lens. The detector lens is a combination of spherical and cylindrical lenses that generate a slit beam on the position-sensitive detectors (PSDs). According to Kaufmann (1997),

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the lateral-effect photodiode, also known as a PSD, is used to determine the position of the centroid. Two PSDs are used to compensate for shadowing of one of the detectors. Measurements are extracted from the 3D point clouds for a specified set of measurements. Size-selection tables have been developed based on ISO 8559.

Hamamatsu developed the BL scanner for women's upper torso and tight undergarments. They have worked with the Natick Soldier Center to compare their BL system with the Cyberware system used at Natick. According to a study comparing the Hamamatsu BL scanner and the Natick Cyberware scanner (Paquette *et al*., 1998), the Natick Cyberware scan system generally results in measurement values less than those obtained with traditional anthropometry. The Hamamatsu BL scanning system, however, tends to produce either similar or larger circumference measurements than those observed for traditional anthropometry. The software performed best on chest and hip circumferences, but it still had difficulty with neck circumferences. Considering measurement variability, the results of the study indicated that the Hamamatsu BL system tended to produce the widest dispersion of measurement values.

5.4 Laser-based systems

5.4.1 Cyberware

Laser scanning methods are used in the Cyberware WB4, WB4 Color, and WBX systems. The scanner projects a line of laser light around the body (Istook and Hwang, 2001). The laser line is reflected into cameras located in each of the scan heads. Data are obtained using a triangulation method in which a strip of light is emitted from laser diodes onto the surface of the scanned object, and then viewed simultaneously from two locations using an arrangement of mirrors. Viewed from an angle, the laser stripe appears deformed by the object's shape. CCD sensors record the deformations and create a digitized image of the subject. The cameras positioned within each of the four scanning heads record this surface information when the heads move vertically along the length of the scanning volume. The separate data files from each scanning head are combined in the software to produce a complete integrated image of the scanned object (Paquette, 1996). Unlike other scanning system methods, the laser scanner generates RGB color values, a process of identifying color-coded landmarks for data extraction after scanning.

The US Army Natick Research, Development and Engineering Center uses the Cyberware system to develop and analyze body shapes for armor coverage and for other military uniform clothing. The ARN-SCAN, also called Natick-SCAN (NS), was created using toolkits developed by Cyberware. The WB4 system is controlled by Cyberware's Cyscan software which performs basic graphic displays. The software is written in C++ and Tcl/Tk. The scan data are convertible to VRML for web-based applications (Cyberware, 2007).

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It was designed and manufactured as a portable tool for highly versatile and accurate scientific applications and has proven to be invaluable in collecting the data necessary to develop the measurement extraction capabilities required for accurate recruit sizing. However, the scanner has expensive features not necessarily needed on the recruit issue line and requires skilled personnel for its set-up and operation. For this reason, Cyberware developed the WBX version of the scanner in 2000.

Both scanners can be non-contact optical laser scanning systems, although it has been suggested that measurements are extracted more accurately when the body has been previously marked with optical markings. Cyberware manufactures and develops 3D body scanning systems for the apparel industry, garment designers, anthropologists, automotive designers, furniture designers, computer game developers, and medical applications.

5.4.2 Human Solutions

Human Solutions is a German company that has been measuring and modeling humans since 1989. They have developed hardware and software that aids in the collection of data that can be used in the development of products directed towards individualization and personalization. These range from ergonomic applications in the automotive industry to mass customization in the apparel industry (Human Solutions, 2007a).

The RAMSIS system is directed at virtual product design and ergonomic analysis. It was developed in response to the German automotive industry and is now used by many in the automotive industry worldwide. The system is integrated with CAD systems such as CATIA and IDEAS, and has applications for anthropometric databases, posture and movement prediction, interior design, package and seat design, workplace design, and medical design as they relate to ergonomic analysis. BodyBuilder and Anthropos are additional modules that help maximize ergonomic performance. (Human Solutions, 2007a).

The Vitus LC 3D body scanner scans the human body from front-left, front-right, back-left, and back-right simultaneously using three sensor heads, allowing a 360° image of the person being scanned. It uses optical triangulation with a laser light stripe. The subject is scanned in a total of 11 seconds, which helps to minimize overall movement. When used in combination with the Retailor/Intailor measurement software, there are a variety of measurement extraction functions available. There is automatic determination of approximately 40 body measurements (Human Solutions, 2007b).

The Vitus XXL 3D body scanner was developed to generate extremely precise 3D images of the human body according to ISO 20685. It also uses optical triangulation with a laser light stripe, capturing all images simultaneously with eight sensor heads. The subject is scanned from top to bottom in less

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than 12 s. More than 140 measurements can be automatically extracted according to ISO 7250 and ISO 8550 standards. In addition, 70 body landmarks are determined automatically. The use of Anthroscan body measurement software allows additional functions for the extraction of body measurements (Human Solutions, 2007c)

5.4.3 Vitronic

Vitus is Vitronic's 3D optical-scanning system which also automatically calculates body dimensions. The measurement method used is optical triangulation with laser, using an eye-safe laser (class 1) and CCD cameras, traveling vertically. It has an automatic calibration facility and an option for color texture. Vitronic has developed its own software for visualization and manipulation of 3D scans. It allows visualization of up to 16 million triangles and 3D points, processing of textures, and data export in various formats, such as VRML and JPG. It is a fast and precise measurement system that interfaces with CAD systems for clothing design.

5.5 Microwave-based systems

5.5.1 Intellifit

Intellifit's Virtual Fitting Room (VFR) is a cylindrical holographic imaging technology that can perform a 360° whole-body scan in less than 10 s. This technology was developed by Pacific Northwest National Laboratory for the US Department of Energy as part of their research related to imaging through various materials. The portion of the technology specifically applicable to the apparel industry was licensed for use by Intellifit. The Intellifit scanner has a vertical arm that rotates around the body. This arm is filled with antennae that bounce signals off the body reflecting more than 200 000 points in space. The array/transceiver illuminates the human body standing within the cylinder with extremely low-powered millimeter waves – a class of non-ionizing radiation not harmful to humans – that penetrate clothing and reflect off the body. The reflected signals are collected by the array/transceiver and sent to a high-speed image processing computer where the Intellifit software converts that 'point cloud' into dozens of precise body measurements forming a high-resolution 3D image of the body (Pacific Northwest National Laboratory, 2004; Intellifit 2007).

5.6 Advantages of body scanning technology

Compared with traditional measurement methods using measuring tapes and calipers, laser scanning systems have the advantage of speed. As shown in

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Table 5.2, all current systems can capture an image of the human body in mere seconds. The scanned subject might even be disappointed because the experience seems to be over so quickly. However, speed is important here, because it aids in the reduction of body movement artifacts that can contribute to measurement error. The speed of the scan time also allows many subjects to be scanned in a short period of time.

Scanning and data extraction time vary between type of system. Light projection systems are usually faster than laser scanning systems during the scanning sequence of an object; however, the measurement extraction time for several is longer than that of most laser scanning systems. It appears that light scanners generally need more time to calibrate and compute when processing data. Nevertheless, the majority of the scanners can scan a subject and extract a set of predefined measurements in less than 2 min. An additional advantage is that the scanned image remains available, indefinitely (except in the case of Intellifit), for re-use at any point in time. These 3D-image data are valuable to the subject/consumer, as well as product developers, for a number of reasons.

Consumers may find it much easier to purchase custom-fit products (i.e. swimsuits, wedding dresses, jeans, tailored suits, etc.) in the near future, if they have already been scanned and their image data are available in a

Table 5.2 Comparison by scan times and extraction times

System	Scan time (s)	Process and extraction time (s)	Total (s)
Light projection systems			
$[TC]^2$ – NX16	8		
$[TC]^2$ – NX12			
$[TC]^2$ – 2T4 system	10	30	40
$[TC]^2$ – 3T6 system	10	30	40
Hamamatsu – BL	7	40	47
Telmat – SYMCAD	7.2	15	22.2
Wicks and Wilson – TriForm Body Scan	12	60	72
CogniTens – Optigo 100	6	14	20
Laser projection systems			
Cyberware – WB4	17	30	47
Cyberware – WBX	17	30	47
Vitronic – Vitus Smart	10	30	40
Human Solutions – Vitus XXL	1.3	?	12
Human Solutions – Vitus LC			11
Hamano – Voxelan	10		Up to 60
Polhemus – FastSCAN	30	?	?
Microwave systems			
Intellifit	10		

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database somewhere. Measurement data are only valuable as long as they meet the specific needs of the product being developed. While an infinite number of measurements could possibly be defined and extracted initially from the scan during the scanning process, it is also likely that a special measurement might be needed for a swimsuit, for example, that no one might have considered. With the 3D image available, measurements can be defined at any time, in any way that might be needed.

5.7 Disadvantages of body scanning technology

While body scanning technology has great potential to benefit the fashion industry and aid consumers in obtaining clothing that fits, there are also a number of issues that might be considered disadvantages when compared with traditional physical measurement methods. Some of the disadvantages are related to the type of technology (light, laser, or microwave) and how the image is actually collected.

In the light-based systems, the color of the scan gear, hair, and skin have a significant impact on the collection of the image. If there is too much difference between the scan gear and the skin, or the scan gear is black or dark in color, then it is much more difficult to achieve a good scanned image, since a good image is based on an even, overall reflection of light. Hair is also tricky, since different hair colors reflect light differently. In addition, hair can obstruct the view of important landmarks around the neck and shoulders (in both light and laser systems).

Apparel worn during the scan process is an issue for both laser- and light-based scanning systems, since both will capture the surface of the garment over the outside of the body. Loose garments will increase the dimensions of the measurements that are extracted, regardless of which system is used. The reverse is also true. Garments that are too tight will cause measurements to be smaller than they should be. Because of this, close-fitting but not constricting garments are advised for both systems. In the microwave system (Intellifit) garments are assumed to have no impact on the measurements obtained.

There are usually parts of the human body that can not be ‘seen’ by the vision devices of the scanning system – such as the top of the head, the top of the shoulders, the bottom of the feet, the crotch at the junction of the legs, and the armpits – depending on how many data-capturing devices there are in the system and their locations. The more sophisticated the system, the more expensive it is. To cater for all of these hidden areas, many of the systems have developed algorithms that create image data ‘averaged’ from the captured data around them. This is a simplistic explanation, of course, for a complicated process that primarily aims at filling holes with as little computer effort as possible. Some of the missing data might be ignored

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(such as the top of the head or the soles of the feet) if it does not have any importance or relationship to apparel development/fit.

The importance of 3D body scanning technology is in the ability of the systems to not only capture the 3D image of a human body, but to also extract measurements at precise locations on the human body. Consistency of measuring techniques between the scanners is a significant issue. Among the growing number of scanners that are currently available, significant variance exists in how each scanner captures or extracts specific body measurements (Simmons and Istook, 2003). Some systems depend on physical landmarking before the scan takes place. This allows a human to make an educated decision about the location of important points of measurement or landmarks (such as shoulder point, high-point shoulder, bust point, and waist) and palpate, if necessary, pre-scan. The extraction software for these specific systems then uses the pre-marked landmarks for the measurements they extract.

Other systems (i.e. $[TC]^2$ Body Measurement System) do not require pre-scan landmarking. The extraction software is able to determine certain body landmarks that enable location of most, if not all of the other necessary landmarks required to extract body measurements. There has been much discussion that human landmarking pre-scan is a more accurate method for determining body landmarks, many of which can not be seen on the surface of the body and are often determined by feel. The argument to this is that computers can be depended on to conduct a task in exactly the same way, every time, when studies have shown that even the same trained expert will get different measures with repeated attempts.

An additional issue is the definition used to define the measurements obtained from the 3D body scan. The American Society for Testing and Materials (ASTM) and the International Organization Standardization (ISO) standards that support current sizing systems also contain definitions describing how each measurement should be obtained with physical measuring processes. However, there are currently no published standards on the interpretation of measurements obtained from 3D scanned images. Standards for body and garment dimensions have been developed by ASTM in the US and ISO in Europe. Three-dimensional body scanning brings to the forefront issues concerning these current standards. Most current standards require palpation, or touching of the human body, or the bending of body parts to find appropriate landmarks for the needed measurements. Most scanners are intended to be non-contact to protect the privacy of the individual who is to be scanned. If we are to use the current standards to justify the measuring process in 3D scanning, they just will not work. New standards are needed that will work for 3D scanners globally and both ISO and ASTM are currently working on establishing standards that will enable a common understanding among and between scanners and conventional measuring methods. Until the

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data-capture process of these measurements can be standardized or, at the very least, communicated among the scanning systems, this technology cannot be utilized for its maximum benefit within the apparel industry.

5.8 Uses of body scanning in the apparel industry

5.8.1 Anthropometric sizing surveys

CAESAR study

Large, well-organized groups are using 3D body scanning technology to gather anthropometric data. One project was the Civilian American and European Anthropometry Resource (CAESAR) project. This effort attempted to gather a complete set of data relating to the various shapes and sizes of the Western world's 18- to 65-year-old population. The US Air Force at Wright-Patterson Air Force Base, Ohio, provided a team to conduct on-site measurements using a Cyberware WB-4 whole-body scanner. Companies wishing to participate in the project paid a $40 000 fee and, in return, received raw body measurement data as well as demographic information. Non-participating companies paid as much as $250 000 for the data (Ponticel, 1999).

SizeUK

The national sizing survey of the UK began in 2000 and was completed in 2001 with 11 000 subjects from all over the UK scanned using 3D whole-body scanners that extracted 130 body measurements. The survey was a collaborative effort between the UK Government, major UK apparel retailers, leading academics, and technology companies (Treleaven, n.d.). The aim of the survey was to develop sizing standards that represent the population of the United Kingdom.

SizeUSA

SizeUSA was a national sizing survey in the USA funded by the US Department of Commerce, industry, and academic sponsors. This study, conducted between July 2002 and July 2003, is the most extensive sizing study ever done in the USA. After advancements in body scanning technology, this study cost only $1 million, compared with the $6 million it cost to complete CAESAR, which was actually a smaller study. Performed to benefit apparel, automotive, aerospace, commercial airlines, furniture, and health care industries, $[TC]^2$ scanners were used in locations around the nation to gather measurements from more than 10 000 subjects. Some sponsors included: Jockey, Sears, David's Bridal, Dillard's, Milliken, the US Navy, the US Army, DuPont, Liz

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Claiborne, North Carolina State University, Auburn University, Cornell, Target, JC Penney, Sara Lee, VF Corporation, Russell, Land's End, and Levi Strauss & Co ([TC]^2, 2004).

An interesting feature about this study is that a variety of demographic and psychographic information was also gathered, so that specific groups could be segmented by age, ethnicity, income level, weight class, and other characteristics. Before this study, no study had allowed for a separation of information into demographic groups or specific target markets (Ashdown *et al*., 2003). Thus, SizeUSA was truly revolutionary, giving the apparel industry anthropometric information that is actually representative of the current US population.

SizeKorea

SizeKorea was conducted from March 2003 to November 2004, and included not only the traditional physical anthropometric measuring techniques, but also 3D body scanning (Lee *et al*., 2007). Almost 20 000 Koreans from 0 to 90 years were measured on 119 traditional items, 35 action items and 205 3D items. The aims of SizeKorea were: (1) to gather size and shape information for the Korean body that corresponded to international criteria; (2) to obtain 3D Korean body data of importance to many industrial areas; and (3) to build a database of body measurements for the development and revision of industrial products and system standards (Korean Agency for Technology and Standards, 2006).

Other studies

Other studies are either in the planning stages or have started using 3D technologies. SizeMexico data collection began in Guadalajara and some initial analysis has already been done (Anderson and Newcomb, n.d.). Canada, Australia, Brazil, and other countries plan to follow suit soon. This is only the beginning of a trend that will probably be repeated on a regular basis around the world.

5.8.2 Mass customization strategies

New technologies often have an end result of shortened life cycles and, thus, increase the need for new product development processes. However, technology can also *inspire* innovation and the new product development process by making things possible that were not possible before the technological advancement (Urban and Hauser, 1980; Virtual Fashion Technology, 2007). Body scanning technologies have certainly motivated significant advancement in the area of sizing, fit, and product visualization. Apparel retailers have

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used body scanners as marketing tools to improve customer satisfaction, obtain more information about their unique target customers, and enable garments designed for custom fit.

- Levi Strauss premiered body scanning in their San Francisco, California store, providing customers the opportunity to be scanned and have a pair of custom jeans made. This program, called Levi's Original Spin, made others retailers stand up and take notice (Lajoie, 1999).
- From October through December of 2000, Lands' End sponsored the 'My Virtual Model Tour 2000' as the world's first body scanning truck. Individuals were scanned with an Image Twin scanner and experienced the Lands' End 'My Virtual Model'. This proportionally sized virtual model was created with scan measurements and could be used to try on clothes, create outfits, and determine what size to buy through the Lands' End catalog and website. Lands' End called it 'the future of fitting rooms today!' (Bobbin, 2001).
- Brooks Brothers, a primarily men's clothing chain, placed a body scanner in their flagship store on Madison Avenue in New York City in 2001. The company originally began with custom tailored suits and has now moved on to dress shirts (Cohen, 2004). The process has been more successful than expected and plans are in place to offer custom-fit women's suits. Products can be delivered in 10–15 days from order and the company is working to reduce that time further.
- Another high-end menswear company, Benchmark Clothiers, has also purchased scanners that they use to scan customers in-store to offer customized garments (Cohen, 2004; $[TC]^2$, 2005). They intend to connect their store-front sites to their manufacturing and distribution facilities via the Internet and have plans to open store fronts across the USA.

Other retailers, manufacturers, and designers are also using 3D body scanning technology to create custom-fit garments. Lori Coulter True Measure out of St Louis, Missouri, USA creates swimsuits designed not only to fit each woman's unique shape but also to flatter their shape (Lori Coulter, 2007). Bodymetrics, a UK company, offered custom jeans and 3D garment visualization at Selfridges in London. They have also opened a site in Paris at Le Bon Marché. Not only can the customer obtain a pair of jeans with a custom fit, they may also select the fabric, rise, and leg style ($[TC]^2$, 2005). In addition, they have signed on designers such as Vivienne Westwood, Nick Tentis, and Nick Holland to offer custom-fit product using this technology at Harrods. Products may be delivered within six weeks rather than the customary three months for couture items (Bodymetrics, 2007).

A related process to mass customization is size prediction. If companies already create many stock-keeping units (SKUs) of a product, like Levi's, it

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makes sense to determine if an appropriately fitting size garment already exists before creating a custom cut for a pair of jeans. The process matches customers with garments by comparing measurements. Thus, development of size prediction came about. This process helps the customer find the best product style and size that will most likely provide the fit that they have described as their desired fit (tight, loose, low waist, etc.). For some companies, this is where the process ends (David's Bridal, the military, After Hours Formal). The customer either finds the garment that they like the fit of or they do not. Other companies take the second step and create a custom-fit garment for the customer, once it has been determined that they have no product that would actually fit as a ready-to-wear garment.

One example of using body scanning for size prediction was the collaboration between Intellifit, a producer of millimeter-wave body scanning technology, and several apparel retailers, including David's Bridal, After Hours Formal, Federated Department Stores, and Levi Strauss & Co. As part of this collaboration, Intellifit established several scanning locations at its retail partners. Customers were scanned in these locations and, after scanning, received a printout of the brands, styles, and sizes that fit them the best. This should have benefited not only the customers, but also the retail partners, since measurement data were collected for their actual consumers. This measurement data could then be used to revise grading or sizing strategies to best fit actual consumers.

5.8.3 Fit and shape evaluation

Universities and businesses across the world are working on projects using 3D technologies that relate to fit and shape evaluation in some form or another. Professors Susan Ashdown and Suzanne Loker of Cornell University, New York have been working to determine the criteria by which apparel companies develop their sizing systems and provide suggestions for improvements. Their research centers on how body scan data can play a role in satisfying consumers' desires regarding fit (Cornell, 2007).

Researchers at Auburn University, Alabama have been studying mass customization business processes, body scanning, fit preferences and the shapes of female consumers through grants funded by the US Department of Commerce and the Alabama Agricultural Experiment Station (Auburn, 2007). They have been working to make a connection with the fit preferences of consumers, their shapes, demographics, and measurement data.

Three-dimensional body scanning has not only inspired advancement in the area of sizing and fit by enabling sizing studies, it has also contributed to the development of other technologies. For instance, a software program known as the Female Figure Identification Technique (FFIT©) for Apparel was developed at North Carolina State University and has implications for

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size and shape analysis using body scanning data (Simmons, 2002; Simmons *et al*., 2004). Even though the program was created before the release of SizeUSA data, it is applicable for the analysis of SizeUSA body scan data. The first software of its kind, this system uses body scan measurement data to classify subjects into one of nine distinct body shapes. Specifically, it only needs six body measurements (bust, waist, hip, high hip, stomach, and abdomen) to classify a person as a particular body shape (Hourglass, Bottom Hourglass, Top Hourglass, Spoon, Rectangle, Diamond, Oval, Triangle, or Inverted Triangle). Because it only relies on these six measurements, the shapes are defined at the most elemental level (Simmons, 2002; Simmons *et al*., 2004). Work continues on this software to include men in the shape classification, as well as more complicated 3D shape definitions.

Three-dimensional to two-dimensional automatic pattern unwrapping is a $[TC]^2$ software system that became available with the NX12 scanning system launched in 2004. The software allows the user to define a garment on a 3D body image that was obtained using a 3D whole body scanner. It has the unique ability to automatically extract custom-fitted blocks/slopers and finished patterns without using measurements, but instead direct 3D to 2D data conversion. Design features such as pleats and darts can be predefined for the pants pattern, along with fit and ease parameters. The 3D garment can be automatically flattened into a 2D pattern in the Drawing Interchange File (DXF) format and then can be imported to a CAD system such as Gerber AccuMark PDS. Unlike traditional pattern development that only accommodates one shape of the body and changes measurements according to that one shape, this system allows for the individual's body shape to be considered as well as their measurements (Smith-Outling, 2007).

An additional technology, strongly dependent on body scanning, is the development of fit forms made exactly to the shape of a retailer's or manufacturer's fit model. The purpose of this is an effort to reduce product development time by allowing fit evaluation of garments at offshore manufacturing sites without repeated shipping of sample garments to an approval site. If each manufacturing site where a specific line is produced has a fit (dress or draping) form of that line's fit model, most of the sample fittings can be done at the manufacturing site, reducing a great deal of product development time and related expense. The process requires that fit models be scanned using one of the previously mentioned 3D whole-body scanning technologies. The 3D image obtained from the scan is then converted to a foam or styrofoam form for company approval. Once the purchasing company has perfected the shape of the form, a mold is created so that many identical forms can be made. The resulting forms have been dehumanized (are now symmetrical etc.) and can be created with linen coverings or may appear like flesh with a malleable body (Alvanon, 2007; Shapely Shadow,

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2007). This technology has been used by companies such as Dillards', Victoria's Secret, Nordstroms, and Brylane.

A related technology produced to further enable reduced product development time is called FastFit 360°™ created by Shapely Shadow of Malibu, California. The software system allows digital video to be captured of a rotating image of a garment on a fit form or model. The captured video is then converted into a number of rotating images of the garment, within seconds. The resulting output (several formats are available) can be sent through email or viewed online for fit evaluation. The images can be zoomed in and out, and rotated 360° for better evaluation. When the video is taken of the garment on the 3D customized fit form from the scan of the fit model, the process is most likely to be successful at providing accurate fit evaluation.

5.8.4 Virtual modeling and online fit analysis

Several CAD systems – such as Optitex, PAD, Browzwear, Tukatech, and others – have developed software for the apparel industry enabling visualization of garments on 3D avatars. These avatars can be adjusted to generally mimic a specific set of fit measurements by fine-tuning points of measure, such as the bust, waist, hips, abdomen, etc. Two-dimensional garment patterns can then be set to 'sew' together on the body demonstrating the drape of the fabric and the potential fit of the garment. In some of the systems, 'skin' appears to show through where the garment does not fit. As the technology has advanced, import of actual 3D body scan image data has become possible so that fit of a specific design can be virtually assessed on the actual fit body. While virtual fit assessment is still significantly different than a physical fit testing session, virtual assessment on a 3D scanned image of a real person has appreciably more value than that done on a created avatar.

My Virtual Model was one of the earliest efforts of the virtual try-on concept for consumers available online from Lands' End, Levi Strauss, Lane Bryant, and others. These systems were designed for style selection, not sizing, and so work without body scan or other 'real' measurement data. The interactive process generally requires customers to enter information about their body shapes, such as small or large bust, waist, and hips, torso length and shoulder width. In some cases, the customer is allowed to choose hair color, hair style, facial characteristics, and skin tone. A general image of the customer's body shape displays on the screen for confirmation or modifications, and this body shape can then be dressed with selected clothing. This process allows customers to get an idea of how their garment selection might look on their body shape.

When body scan data become part of the online visualization process, the virtual image will become more realistic. Garments will then have to have measurement data linked with the visual data so that size selection can be

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more accurate. Customers will be able to view their own 3D image (not an idealized model); rotate it to see front, back, and side views; and select the style and size that fits best.

5.9 Conclusion

The purpose of this chapter was to provide information on currently available 3D whole body scanning systems that might have application in the apparel industry. There are applications for body scan data outside the apparel industry as well. The airline, automobile, and tractor industries have used scan data to develop seats that are optimized for the highest number of body types. The entertainment industry has used scans to develop animations, most recently of sports stars for video games. Health clubs have applied body scan technology to evaluate the effects of workout programs using 'before' and 'after' comparisons. The use of 3D whole-body scanners is still in developmental stages; many future applications have yet to be realized.

Three-dimensional body scanning technology has shown great potential for use in the apparel industry. The technology is an effective tool for measurement of the human body. It has the advantages of speed, accuracy, and consistency of measurement data. In addition, technical measurements are simply extracted without professional knowledge of traditional measurement methods. Extracted measurement data are beneficial for use in the development of new sizing systems, as well as in the production of customized garments.

Reducing or eliminating the landmarking process, missing data, and inconsistencies related to movement artifacts are goals held by most of the developers of this technology. In addition, clear measurement definitions and the development of standards between apparel industries and companies developing 3D body scanning systems are essential for the long-term use of this technology and the other design and manufacturing processes that the technology enables.

Body scanning technology enables studies of human body shape, collection of 3D-image data, and extraction of measurement data. This information benefits the apparel industry by providing better tools to create clothing that fits, in addition to tools to evaluate the fit of clothing. It has also encouraged the development of other related technologies, all of which are helping to reduce the time it takes to get the product from the concept stage to the production stage.

5.10 Sources of further information and advice

- ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 18428-2959, USA. Web: http://www.astm.org
- International Organization for Standardization (ISO), 1 rue de Varembé,

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Case postale 56, CH-1211 Geneva 20, Switzerland. Web: www.iso.org
- $[TC]^2$, 211 Gregson Drive, Cary, NC 27511, USA. Web: www.tc2.com
- Bodymetrics. Web:www.bodymetrics.com

5.11 Acknowledgments

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6

Computer-aided garment design using three-dimensional body models

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6.1 Introduction

This chapter describes a system developed by a research team at Queen's University Belfast for creating designs relative to an underlying three-dimensional (3D) form. In the context of garment design, the underlying form is a model of the human body or mannequin. However, the approach can be applied in other applications where the underlying form may be, for example, a packaging product or the frame of a car seat. The system has been commercially developed for shoe design but in the discussion below, the focus is on garment design. Certain restrictions apply. A torso model is used and the garment designs are relatively close fitting. Designs are created by using computer-assisted drawing directly on the 3D body model.

In the following description of the system, a hierarchy of geometric entities is used to construct a design. At the lowest level, a user enters 'points' into the system based on a visual evaluation of the current cursor location. Successive points entered in this way enable a continuous 'curve' to be constructed, displayed and interactively assessed by the user during the point-entering stage. The spans between neighbouring points on a curve are termed 'edges' and are the building-blocks of garment pieces or panels. These are defined in terms of a closed boundary created by an ordered set of edges. A panel has a set of polygons that completely fills its interior. Note that the adoption of edges as the basis for defining a panel boundary enables a panel to be constructed along part of a particular curve and not necessarily along its entirety. The panels created are 3D shell structures that ultimately have to be made-up from 2D plane fabric material, requiring distortion of the material and fitting procedures to take up the 3D shape. These issues are considered so that practical patterns for the designed panels can be defined. In addition, a single edge can be used in the definition of a maximum of two panels – one on either side. Thus, the connectivity between panels can be unambiguously defined, making for an easier link to downstream manufacturing stages.

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Section 6.2 considers related work in data entry and pattern construction. Section 6.3 considers the primary processes of defining points on or off the body surface while Section 6.4 explains how panel surfaces can be created from defined points, curves and edges. The construction of realistic patterns and accurate texture rendering that embodies flattening distortion are covered in Section 6.5. The chapter concludes with an example garment and a discussion of future work.

6.2 Related work

While there has been considerable work in the separate areas that are necessary for a fully working integrated garment visualisation and design system, it is only the specific aspect of defining garment pieces and their associated patterns that is addressed here. The importance of this topic has been recently appreciated. Volino *et al.*[1] propose a framework for placing patterns around a mannequin, seaming the patterns together and performing drape using mechanical simulation. However, it is acknowledged that advanced 3D garment sketching tools are required for dressing a mannequin directly in the virtual world. This would get around the problems of placement and assembly of complex garments around a virtual character. In a review paper addressing the future research required in clothing simulation, Choi and Ko[2] indicate that there is an urgent need for simple design techniques that can be used by non-experts and that the conversion of designed garment pieces to patterns through surface-flattening techniques is crucial for the quality of the final manufactured garments. Little work has been reported on methods for directly constructing patterns associated with defined regions on the body surface. Au and Yuen[3] describe a process for fitting Bezier patches to a torso captured as a point cloud but do not take the resulting patches forward towards a garment design. Kim and Kang[4] introduce a method for the automatic generation of bodice patterns for a torso approximated by a cylinder. A useful aspect of this work is the incorporation of body landmarks for alignment of the patterns. The difficulty of generating an optimum pattern that includes darts is noted, as this frequently requires the skill and experience of traditional garment designers and tailors. Wang *et al.*[5] report the development of a 3D design tool that creates garment patterns directly in 3D space through 2D drawing strokes. Profile curves expressing plane sections through a garment panel are drawn in 2D and a smooth mesh surface interpolating the defined curves is created. Precautions need to be taken to avoid collisions between the garment panel and the underlying body. A limitation of the work is that users may want to specify profiles whose points do not lie on the same plane, requiring more complex specification tools.

The approach taken by the present authors[6] provides a method for drawing directly on the 3D body that is intuitive and straightforward. By only offering

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a drawing space that is offset from the body, the problem associated with the creation of garments close to the body is greatly reduced. The ability to place darts at any location combined with strain energy minimisation methods for flattening[7,8] produces garment panels that are available for subsequent visualisation and assessment.

6.3 User interface for three-dimensional design

The basis for the present design process fundamentally depends on the underlying 3D body surface description. The mathematical specification of the body must be of a bi-parametric form. Typically, such body surfaces can originate from two sources:

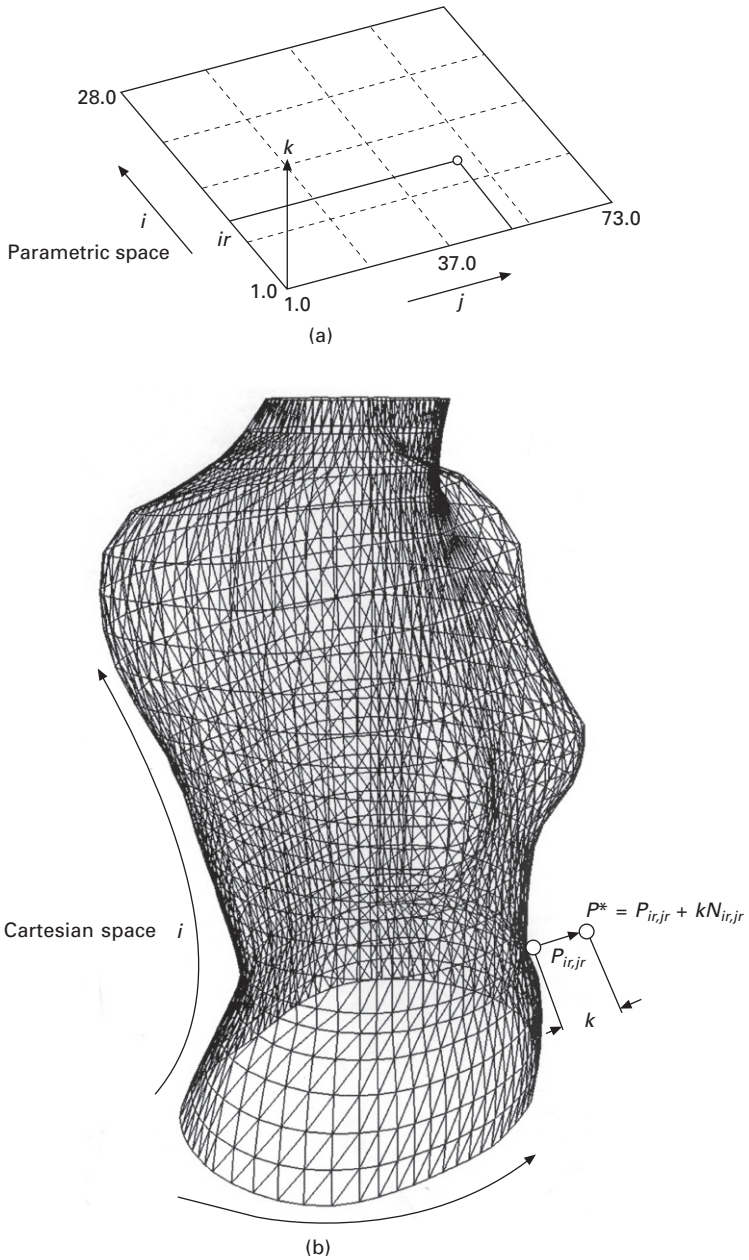
(a) another CAD system;
(b) 3D digitising machines.

So for instance, if it is intended to design a fully rendered representation of a new detergent bottle, then the underlying bottle shape can be generated from a conventional engineering design system. Alternatively, if a bespoke flak jacket is to be designed for a new army recruit, then the body torso shape can be captured by a 3D digitiser.

Irrespective of which source provides the data, topologically the underlying body is the same. Loosely, this can be considered as a distorted cylinder where the two parametric directions are aligned with an angular displacement around the body and a linear distance, usually in the vertical direction. Care must be taken when considering the detail that is required for the underlying body and account should be taken of the ultimate application. For instance, it is not necessary to pick up ribcage perturbations of the human body when designing garments. From experience, the authors have found that 28 sections containing 72 points are sufficient to represent most human torsos. This would correspond to placing a person in a digitising machine and capturing vertical sections consisting of 28 points from waist to neck at 5° rotational intervals. However, with the speed and memory capacity of modern computers, there is virtually no limit to these dimensions and, thus, the complexity of the body surface to be used.

Although an array of discrete points has been used to represent the body surface, a continuous surface can be approximated between these points by adopting computational geometry techniques such as B spline fitting.[9] Thus it is possible to construct a dual form for representing the underlying body – a bi-parametric plane and the actual 3D surface. Figure 6.1 describes this process where the dimensions referred to above, 28×73, have been adopted. Note that to provide rotational continuity, the first column of data is repeated as the 73rd column. Hence, when a point is specified on the bi-parametric

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6.1 Mapping of parametric space coordinates to Cartesian space.

plane, there will be an equivalent point on the 3D surface. The process of interpolating a point within the array of discrete points representing the 3D body involves the following steps.

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6.3.1 Construction of a body point $\boldsymbol{P}_{ir,jr}$

Assume for the present that the point being specified is to lie on the body surface and, referring to Fig. 6.1:

1. Define an array of discrete 3D points $\boldsymbol{B}_{i,j}$ that describes the surface, where i and j are integers in the ranges $1 \le i \le 28$ and $1 \le j \le 73$.
2. Specify real number values for the i and j parameters (ir, jr), for which a point $\boldsymbol{P}_{ir,jr}$ on the body surface is to be determined.
3. Determine the integer parts (i, j), respectively, of the real values (ir, jr).
4. Construct three geometry matrices for the x, y and z co-ordinates of the appropriate 4×4 part of the $\boldsymbol{B}_{i,j}$ array. If the point at (i, j) has coordinates $(Bx_{i,j}, By_{i,j}, Bz_{i,j})$, then the geometry matrix $\boldsymbol{Gx}_{i,j}$ for modelling the x coordinate is

$$\boldsymbol{Gx}_{i,j} = \begin{bmatrix} Bx_{i+2,j-1} & Bx_{i+2,j} & Bx_{i+2,j+1} & Bx_{i+2,j+2} \\ Bx_{i+1,j-1} & Bx_{i+1,j} & Bx_{i+1,j+1} & Bx_{i+1,j+2} \\ Bx_{i,j-1} & Bx_{i,j} & Bx_{i,j+1} & Bx_{i,j+2} \\ Bx_{i-1,j-1} & Bx_{i-1,j} & Bx_{i-1,j+1} & Bx_{i-1,j+2} \end{bmatrix} \quad [6.1]$$

   Similarly, geometry matrices $\boldsymbol{Gy}_{i,j}$ and $\boldsymbol{Gz}_{i,j}$ can be constructed for modelling y and z coordinates.
5. Using these matrices, the B spline method provides an internal point by the specification of two parameters (s, t) for the surface in question where

$$\begin{aligned} s &= ir - i \\ t &= jr - j \end{aligned} \quad [6.2]$$

   Considering the x coordinate as an example, a precise x coordinate is obtained as

$$x_{ir,jr} = \boldsymbol{S}\boldsymbol{M}\boldsymbol{Gx}_{i,j}\boldsymbol{M}^{-1}\boldsymbol{T}^{T} \quad [6.3]$$

   where $\boldsymbol{S} = [s^3 \quad s^2 \quad s \quad 1]$, $\boldsymbol{T} = [t^3 \quad t^2 \quad t \quad 1]$ and $\boldsymbol{M}$ is the B spline basis matrix

$$\boldsymbol{M} = \frac{1}{6}\begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 0 & 3 & 0 \\ 1 & 4 & 1 & 0 \end{bmatrix} \quad [6.4]$$

To obtain the Cartesian point $\boldsymbol{P}_{ir,jr}$ for the parametric point (ir, jr), the above B spline fitting process is similarly applied to the y and z geometry matrices $\boldsymbol{Gy}_{i,j}$ and $\boldsymbol{Gz}_{i,j}$ using the same parameter matrices $\boldsymbol{S}$ and $\boldsymbol{T}$ to obtain

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$$\boldsymbol{P}_{ir,jr} = \begin{bmatrix} x_{ir,jr} \\ y_{ir,jr} \\ z_{ir,jr} \\ 1 \end{bmatrix} \quad [6.5]$$

6.3.2 Construction of an offset body point $\boldsymbol{P}^*_{ir,jr}$

By constraining the mouse movement to operate within the bi-parametric plane, the software generates a 3D cursor that moves only on the body surface. However, to extend the functionality, a Cartesian point $\boldsymbol{P}^*_{ir,jr}$ can also be set, that is at a controlled offset along the surface normal from the body. The user prescribes a specified offset using mouse button presses. The construction of the surface normal $\boldsymbol{N}_{ir,jr}$ at the parameter values (ir, jr) is achieved by first determining the two surface tangent vectors $\partial \boldsymbol{P}_{ir,jr}/\partial s$ and $\partial \boldsymbol{P}_{ir,jr}/\partial t$, where the vector components are obtained by considering each Cartesian dimension in turn as in Eq. [6.3] above. For the x components of the two tangent vectors

$$\begin{aligned} \frac{\partial Px_{ir,jr}}{\partial s} &= \boldsymbol{S'}\,\boldsymbol{M}\,\boldsymbol{Gx}_{i,j}\,\boldsymbol{M}^{-1}\,\boldsymbol{T}^T \\ \frac{\partial Px_{ir,jr}}{\partial t} &= \boldsymbol{S}\,\boldsymbol{M}\,\boldsymbol{Gx}_{i,j}\,\boldsymbol{M}^{-1}\,\boldsymbol{T'}^T \end{aligned} \quad [6.6]$$

where $\boldsymbol{S'} = [3s^2 \quad 2s \quad 1 \quad 0]$ and $\boldsymbol{T'} = [3t^2 \quad 2t \quad 1 \quad 0]$. This equation is repeated with the y and z geometry matrices, $\boldsymbol{Gy}_{i,j}$ and $\boldsymbol{Gz}_{i,j}$, to get the y and z components of the tangent vectors, $\partial Py_{ir,jr}/\partial s$, $\partial Py_{ir,jr}/\partial t$, $\partial Pz_{ir,jr}/\partial s$, $\partial Pz_{ir,jr}/\partial t$. These components are then used to define the tangent vectors as

$$\frac{\partial \boldsymbol{P}_{ir,jr}}{\partial s} = \begin{bmatrix} \dfrac{\partial Px_{ir,jr}}{\partial s} \\ \dfrac{\partial Py_{ir,jr}}{\partial s} \\ \dfrac{\partial Pz_{ir,jr}}{\partial s} \\ 1 \end{bmatrix}, \quad \frac{\partial \boldsymbol{P}_{ir,jr}}{\partial t} = \begin{bmatrix} \dfrac{\partial Px_{ir,jr}}{\partial t} \\ \dfrac{\partial Py_{ir,jr}}{\partial t} \\ \dfrac{\partial Pz_{ir,jr}}{\partial t} \\ 1 \end{bmatrix} \quad [6.7]$$

The unit normal $\boldsymbol{N}_{ir,jr}$ to the surface is constructed by taking the vector product of these two tangent vectors

$$\boldsymbol{N}_{ir,jr} = \frac{\dfrac{\partial \boldsymbol{P}_{ir,jr}}{\partial s} \times \dfrac{\partial \boldsymbol{P}_{ir,jr}}{\partial t}}{\left| \dfrac{\partial \boldsymbol{P}_{ir,jr}}{\partial s} \times \dfrac{\partial \boldsymbol{P}_{ir,jr}}{\partial t} \right|} \quad [6.8]$$

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The position $\boldsymbol{P}^{*}_{ir,jr}$ of an offset point for any offset value k is

$$\boldsymbol{P}^{*}_{ir,jr} = \boldsymbol{P}_{ir,jr} + k\,\boldsymbol{N}_{ir,jr} \quad [6.9]$$

In practice, the operation of this interface has proven to be effective for quickly accessing the relevant design space for a specified 3D body. The computations can be performed in real time so as to provide a smooth user interface. Furthermore, the information produced, namely a surface location and a normal direction, can be exploited further to provide a very effective viewing control functionality.

6.4 Creating garment panels

6.4.1 Overview of designing garment panels

The process described above provides a method for specifying 3D points on or at a nominated offset from the body surface. It is this relative space within which a garment structure will be defined in terms of geometric entities. To progress a design, points are the fundamental entities that a user supplies to define curves. With the ability to pick existing points as well as entering new points, connectivity between curves can be defined. Inevitably, curves may have to be trimmed to form part of the boundary of a panel entity. This is facilitated by using edges as the basis for defining a contiguous and closed boundary for the panel.

For a designer to detail a 3D curve, it is only necessary to move the 3D cursor to the required start position of the curve, depress a mouse button and deposit a 3D point at this location. In the curve-drawing mode, if the cursor is moved on from this initial position, a straight line in space is drawn to the current position of the cursor. While the resulting line may well project through the body and in this case would not be meaningful, a straight line is the only construction possible if there are only two points unless a complex geodesic curve over the body surface is calculated. If a subsequent point is deposited and the cursor moved on again, there will then in fact be three points – the two deposited points and the current position of the cursor. In general, many defining points can be deposited in a similar manner. To fit a smooth curve through such a set of ordered points is a standard problem in computational geometry and there are many procedures available for performing such fitting, either by interpolating through the points or passing close to them.[10,11] Suppose a curve that passes through the points is used. This achieves the required offset at the deposited points but there is no guarantee that this offset will apply to curve segments between the points, i.e. where edges are defined. For the purposes of garment design, it is desirable that an edge definition is determined that maintains a constant offset along its length so that a given degree of fit is achieved while retaining the overall curve's smoothness in the tangent plane of the body. The following technique

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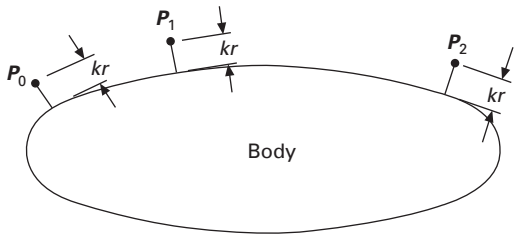
has been derived as an empirical line drawing tool that achieves this while maintaining the required offset. An edge will thus be defined as a piecewise-linear approximation to the original smooth curve segment that spans between a pair of successively entered points.

6.4.2 Construction of a piecewise-linear edge

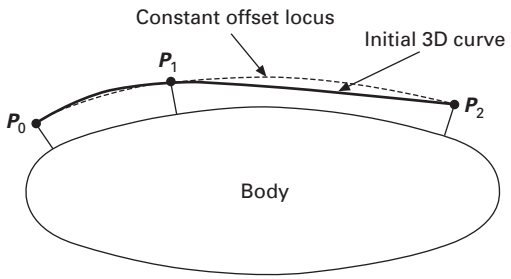
During interactive construction of the 3D curve, a set of points is supplied with the last one being provided by the current cursor position. The interpolated curve through the points is continuously updated according to movement of the mouse. This gives the designer the necessary visual feedback to decide if the curve is lying in the correct location and has the desired shape. Options available are to deposit further points to control the curve's shape or to terminate the curve. In Fig. 6.2(a), a three-point case ($\boldsymbol{P}_0$, $\boldsymbol{P}_1$, $\boldsymbol{P}_2$) is depicted. Note that the curve is only constrained to exhibit the required offset kr at each of the deposited points. The internal curve segments between points will be smooth regardless of the shape of the body underneath as shown in Fig. 6.2(b). During user definition of the three control points for the curve, both parametric (i, j, k) and Cartesian coordinates are known at the deposited points. For display purposes, the continuous curve definition generates a series of internal points for each curve segment between each pair of points that defines the curve. The internal points are used to construct linear steps to facilitate the actual drawing of the curve in Cartesian space only. In order to achieve a piecewise-linear approximation to a curve segment that maintains a constant offset Fig. 6.2(c), the internal points must be redefined. When processed in this way, an internal curve segment is then termed an edge. Figure 6.3 illustrates the process in more detail for the first internal point $\boldsymbol{P}^*$ starting at the first user-defined point, $\boldsymbol{P}_0$. The generation of further internal points for the curve segment follows the same procedure. A defined number of line segments between user-defined points is initially set by the system. By calculating the arc length between $\boldsymbol{P}_0$ and $\boldsymbol{P}_1$ and dividing by this number of segments, the point $\boldsymbol{P}^*$ can be found in Cartesian coordinates by stepping through the continuous curve segment until the appropriate distance is reached along the curve from $\boldsymbol{P}_0$. The objective of the search technique is to find a point $\boldsymbol{P}_t$ that will lie on the normal that goes through a point $\boldsymbol{P}^*$ but will have the required offset kr.

To implement constant offset processing, it is first necessary to determine the parametric coordinates of the point $\boldsymbol{P}^*$. Recall that any triplet (ir, jr, kr) defines a point offset from the body surface (Eq. [6.9]). It is required to determine particular parametric values that correspond to the point $\boldsymbol{P}^*$. The search technique constructs an error vector $\boldsymbol{E}_p$ that represents the distance between the point $\boldsymbol{P}^*$ and the point defined by any triplet (ir, jr, kr). A Newton–Raphson search is used to minimise $\boldsymbol{E}_p$ and, as the point $\boldsymbol{P}^*$ lies in

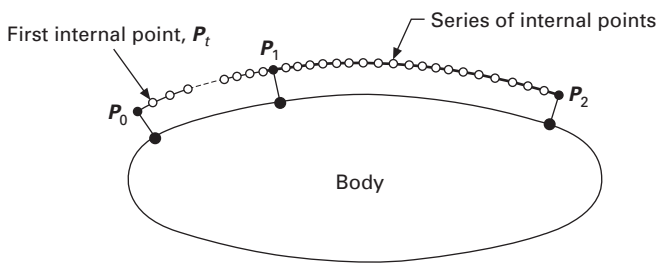
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(a) Initial point specification of 3D curve



(b) Initial 3D curve through points



(c) Final piecewise interpolated 3D curve at constant offset *kr*

6.2 Constant offset processing of 3D curves.

the neighbourhood of $\boldsymbol{P}_0$, reasonably close starting values for the parameters are available, i.e. (*i*0, *j*0, *kr*).

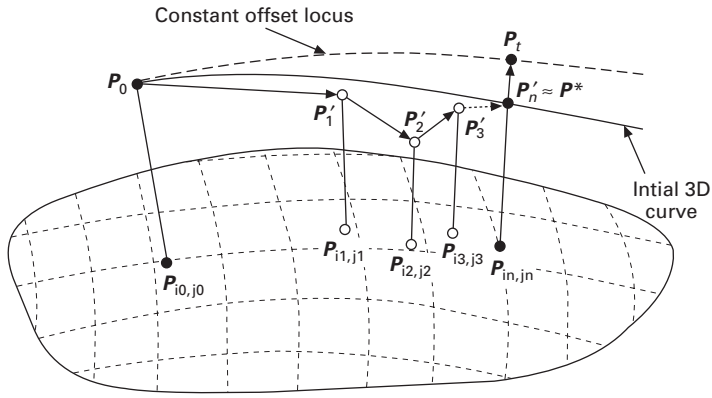
To begin with

$$\boldsymbol{E}_p = \boldsymbol{P}^* - \boldsymbol{P}_0 = \boldsymbol{P}^* - (\boldsymbol{P}_{i0,j0} + kr\boldsymbol{N}_{i0,j0}) \qquad [6.10]$$

The Newton–Raphson search seeks to minimise the *x*, *y* and *z* components of the error vector $\boldsymbol{E}_p$ by varying the step sizes in *i, j* and *k* parameter space depending upon the gradient vectors $\partial \boldsymbol{E}_p/\partial i$, $\partial \mathbf{E}_p/\partial j$, $\partial \boldsymbol{E}_p/\partial k$. Successive iterations of the search technique produce increasingly accurate locations $\boldsymbol{P}_1', \boldsymbol{P}_2', \boldsymbol{P}_3', \ldots, \boldsymbol{P}_n'$ in Cartesian coordinates until the error magnitude is deemed sufficiently small after *n* iterations at which stage it is assumed that

$$\boldsymbol{P}_n' \approx P^* \qquad [6.11]$$

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6.3 Constant offset compilation using Newton–Raphson search.

In practice, the point found will be sufficiently close after less than 10 iterations on relatively smooth body surfaces. The offset parameter found *kn* will generally not equal the required offset *kr* specified when the defining curve points were entered. So to determine the constant offset interpolated point $\boldsymbol{P}_t$, a final offset adjustment is made while still retaining the (*in*, *jn*) coordinates found in the search, i.e.

$$\boldsymbol{P}_t = \boldsymbol{P}_{in,jn} + kr\boldsymbol{N}_{in,jn} \qquad [6.12]$$

Once the first interpolated point $\boldsymbol{P}_t$ has been found, its parametric coordinates (*in*, *jn*, *kr*) can be used as the initial guess for the position of the second interpolated point and so on. In this way, the design system generates the selected number of piecewise-linear segments (20 in the present system) to represent the edge between each successive pair of designed points. There is no appreciable delay experienced at the end of a 3D curve definition when the above constant offset processing of edges takes place.

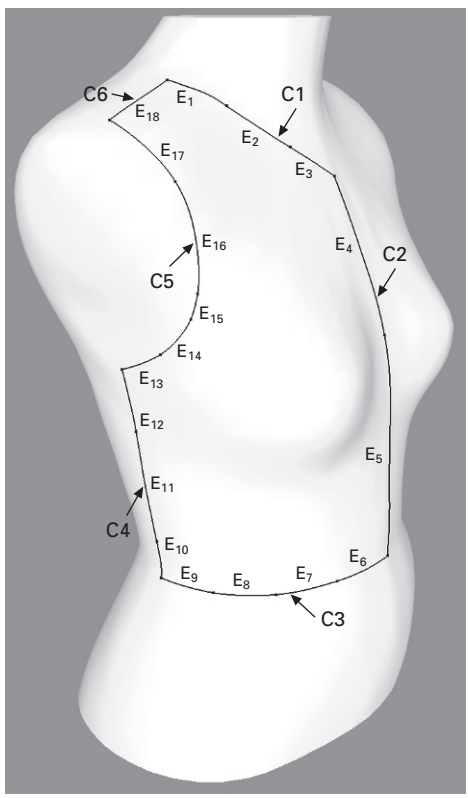
6.4.3 Picking panel edges

Circumstances will arise where it is required to use a given point in the definition of more than one curve (e.g. a corner point on a boundary). Similarly, adjoining panels will often use a limited number of common edges. This requires a modification to the 3D curve design technique whereby predefined points can be picked and used in a 3D curve definition instead of always obliging the user to create new points. Hence, curves can be joined together by incorporating a pre-existing point in the definition of a new curve. Thus during the interactive definition of a curve, it is possible for a user to pick an existing point in addition to entering new points.

In defining panels, a contiguous and closed series of edges has to be

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specified. To avoid the tedious picking of the edges forming the panel boundary, high-level functionality can be implemented to simplify the process of picking panels. This is because many edges are unambiguously connected to neighbouring edges. The data structures representing points and edges can be processed to detect closed boundaries that are used to define panel structures. In the present design system implementation, an efficient panel definition is incorporated whereby a minimum number of picking operations is required by the operator. Consider Fig. 6.4 where a panel boundary is defined by 18 points, 6 curves (C1–C6) and 18 edges (E_1–E_{18}) that have all been set at a constant offset of 2.0 mm. Note the 6 common points that are shared by adjoining curves. To define a panel that is enclosed by these 18 edges, it is only necessary to pick any curve on the boundary. Logic can be applied to build up the complete boundary by progressively adding curves that share a common point with the initially picked seed curve and so on. For this simple case, there is no ambiguity in assembling a panel definition. With more complicated designs however, there may be more than two edges that share



6.4 Initial design specification of panel boundary using points, curves and edges.

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a common point. In such cases, additional information is required to assist in deciding the next edge to use in building up the panel boundary. The addition of an extra point with the cursor, approximately at the centre of the intended panel after the user has picked the seed curve, is usually sufficient to make an unambiguous selection. As a last resort, a full explicit picking of all curves can be made although it does not necessarily have to be performed in the order that links the edges around the panel boundary.

6.4.4 Panel construction

Although the picking operation has been performed using the 3D Cartesian representation of the underlying body and edges, a dual representation is available in parametric space. Because of the constant offset nature of the edges in Fig. 6.4, it is possible to exploit the (i, j) parametric plane form of the edges. In the present system, if m piecewise-linear steps are used to represent an edge between two consecutive design points, then $(m - 1)$ internal points are automatically generated between successive design points. Assume that a panel boundary is comprised p edges. Then a total of $p \times (m - 1)$ additional points are available for the complete boundary definition. When considering what might be an optimal configuration for a panel boundary representation, different sampling patterns are used to pass different combinations of the $(m - 1)$ internal points referred to above depending on the arc length of each edge. For relatively large edges, all $(m - 1)$ points are used. However, for small edges, only the centre point is used.

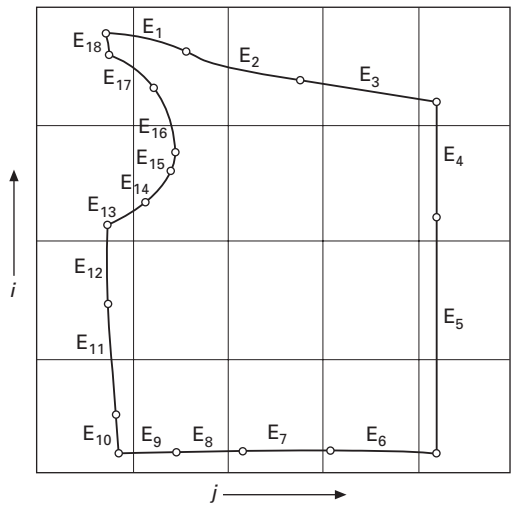
The current application of the design system adopts a value of 20 for m, the number of internal points for an edge. The sample design in Fig. 6.4 has 18 edges constituting the single panel. Thus, a total of (18×19) internal points are available for this particular design. Figure 6.5(a) depicts the (i, j) parametric plane representation of the panel boundary for the design in Fig. 6.4. Figure 6.5(b) illustrates the process of selectively generating additional internal points of edges for the panel boundary. A bounding box is then computed for this boundary. This is used to generate a regular grid of possible interior points for the panel on the (i, j) plane as shown in Fig. 6.5(c). The density of the grid points is a compromise between having:

(a) too dense a grid, which incurs excessive computation times;
(b) too sparse a grid, which will cause the panel image to cut through the underlying body when small offsets are used.

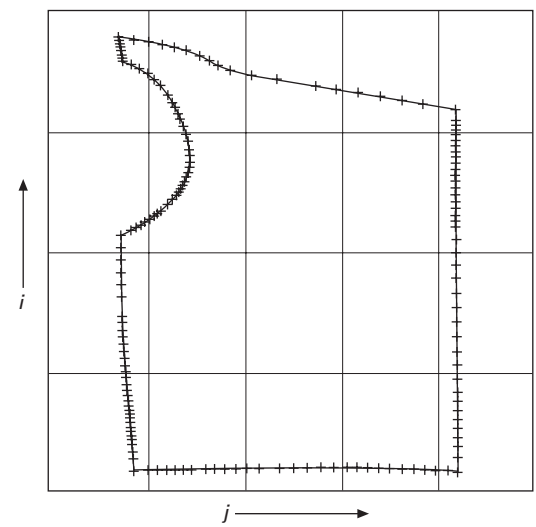
At this stage, some of the grid points will be located outside the panel boundary on the (i, j) parametric plane. Geometric tests can be applied to detect such points and eliminate them from subsequent processing. This results in a two-list representation of the proposed panel. The first one is an ordered list of boundary nodes and the second is a random list of interior

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nodes. This can be used as an input to a Delaunay triangulation technique[12] which generates a set of triangles that represents the complete panel interior and can be seen in Fig. 6.5(d). Generally, the triangulation on the (i, j) plane produces a set of well-behaved triangles. The 3D Cartesian form of this triangulation can now be defined using the vector expression in Eq. [6.12] above. This form is depicted in Fig. 6.6(a). Note that there is certain to be



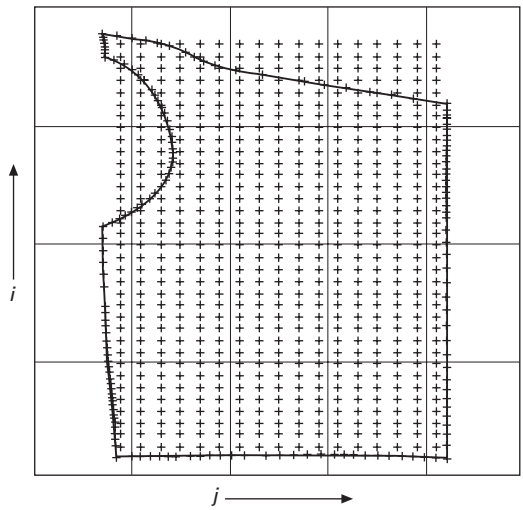
(a) Initial design point and curve specification of panel



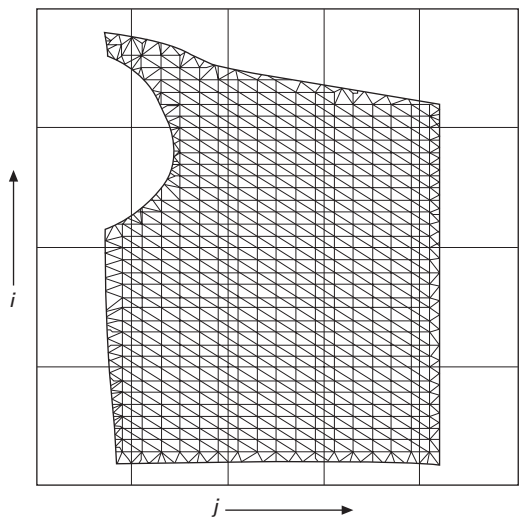
(b) Intensification of panel boundary nodes

6.5 Panel construction on the (i, j) parametric plane.

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(c) Floodfill with panel interior nodes

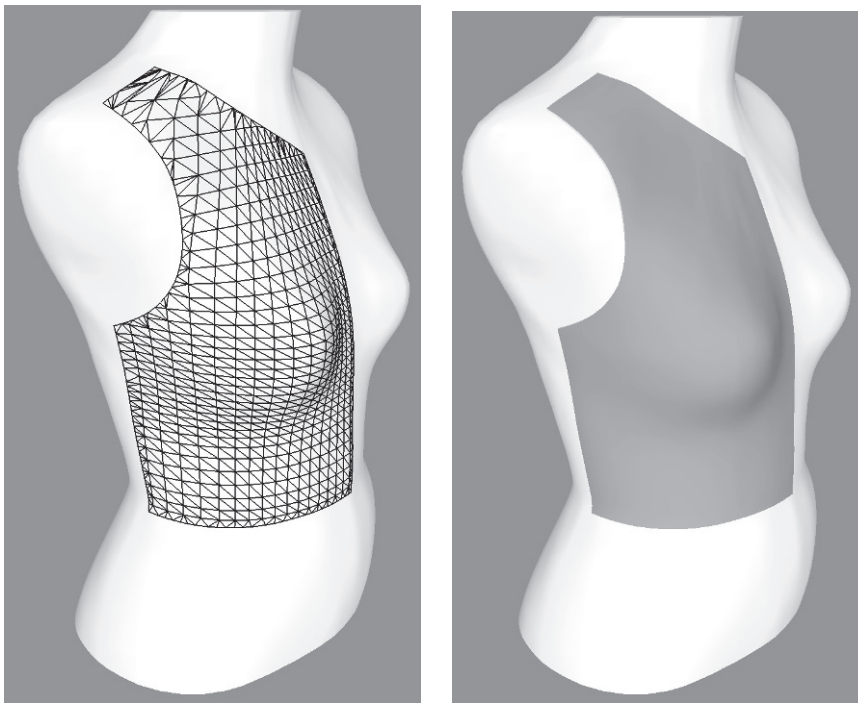


(d) Triangulation of panel boundary and interior nodes

6.5 (Cont'd)

some distortion of individual triangles between the parametric and Cartesian representations. Graphics library functions can now enable the red/green/blue (RGB) rendering of the triangles in Cartesian space to produce a smooth shading blend between neighbouring triangles and so mask the triangulated composition of a panel as shown in Fig. 6.6(b).

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(a) Panel triangulation (b) Panel RGB rendering

6.6 Single-piece panel display relative to underlying body.

6.4.5 Additional panel detail

The panel construction described above can be developed to provide additional detail commonly found in garment constructions. It is possible to define interior boundaries within a panel that can represent cut-outs. These can be incorporated at the Delaunay triangulation stage by supplementing the main panel boundary with these additional boundaries that are ordered in the opposite direction to the main boundary. The triangulation process can detect any triangles within a cut-out boundary and so eliminate them from the final triangle list.

Edge trims can be added by defining a panel thickness which can be interpreted as a lower offset. Triangles can then be generated around the boundary points of a panel which span between the lower offset and the actual offset of the panel.

6.5 Panel flattening and texture rendering

The techniques described in Sections 6.3 and 6.4 above provide 3D drawing tools that take advantage of the particular circumstances of designing relative

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to an existing body form. The 3D definition of garment panels can be exploited further to enable a more integrated approach between design and manufacture by incorporating a technique that can flatten panels. Traditionally, dressmaking and tailoring crafts would perform this function. However, much research has been targeted at converting the geometric definition of the panel with the mechanical properties of the fabric concerned and some knowledge of the intended use of the garment in order to derive an optimal 2D pattern.[8, 13, 14] From a purely geometric perspective, it is almost certain that the 3D panel surface designed will not be developable, i.e. a 2D plane fabric will not be able to take-up the 3D panel surface by bending alone. This implies that some form of fabric distortion has to occur. Different fabrics will exhibit different capabilities to distort. For woven or knitted fabrics, the same fabric will exhibit some degree of directional capability depending on alignment with warp and weft or knit directions. At times the distortion required may exceed the mechanical limits of the fabric, in which case the panel may have to be made-up in two or more pieces or fitting devices such as darts or gussets have to be inserted. Previously, dressmakers or tailors would identify such instances based on an intuitive feel for the fabric concerned.

Increasingly, retailers are demanding greater objectivity to be exercised in the pattern technology function by encouraging a more scientific and engineered approach. The design system described above can provide almost all of the necessary information to develop such an approach. The missing information relates to a specification of the operational conditions under which the garment is intended to perform. Many garment types such as foundation garments and swimwear demand that the garment exerts contact pressure with the underlying body. This can only be achieved by having the garment fabric under tension when worn. The net effect will be that the final 2D pattern will be deliberately undersized for it to induce the contact pressure required. The authors recognise that more work is required to develop this flattening functionality. The main problem areas associated with this are:

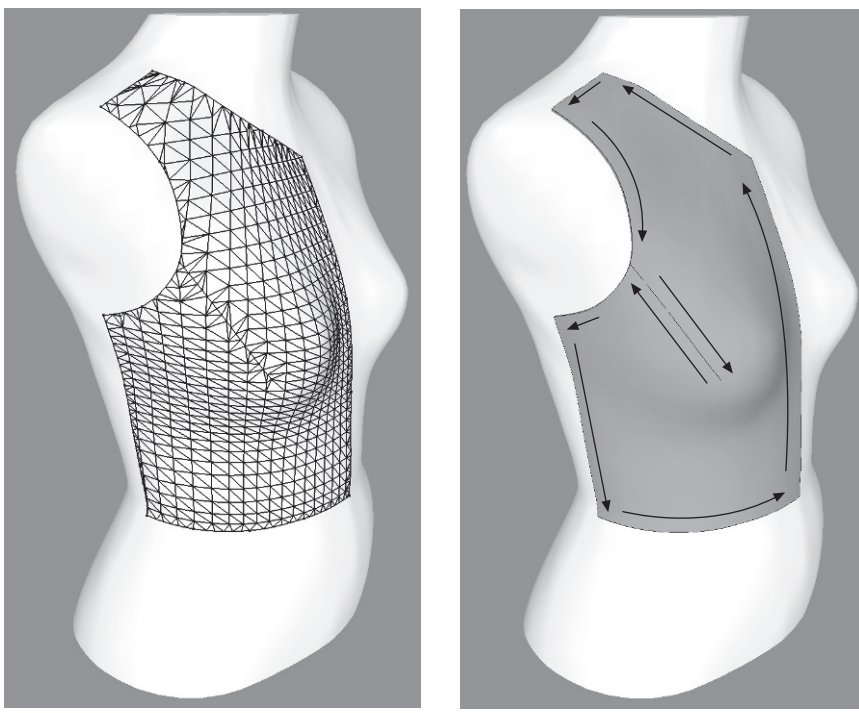
(a) the soft body nature of real people whereby tight-fitting garments actually interact with the underlying body and change its 3D form;
(b) the interpretation of garment functionality as target strain values for different panels and fabrics;
(c) the effects of stiffeners such as seams on overall garment behaviour.

To provide an indication of the type of integration that can be expected between pattern technology and design, for the moment assume that a flattening technique has been successfully applied to the example panel described in Fig. 6.6(b). Two cases will be examined: one where the panel is flattened as one piece and where high distortion can be expected. The other is where a dart line has been specified and less distortion can be expected. Previous research by the authors[7] has examined the problem of flattening panels

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where dart lines have been specified. It is worth noting that for such panels, a complete re-triangulation of the panel is required that incorporates dart lines into the boundary definition. Nodes along the dart line are duplicated, one set represents an inward direction and the second set represents the outward direction. Subsequent Delaunay triangulation will generate triangles that will not span the dart line but will align triangle edges along it. In Fig. 6.7, a modification has been made to the original one-piece panel depicted in Fig. 6.6. Here, a line has been added by picking an existing point along the armhole and creating a line that ends in the interior of the proposed panel close to the bust point. When this curve configuration is picked without any explicit reference to this new dart line, the system can detect the unique character of the new line and interpret it as a dart line for the new panel. In effect, the dart line is added twice to the picked boundary to generate the modified boundary as depicted in Fig. 6.7(b). Figure 6.7(a) reveals the underlying change in the triangulation to allow the dart to be incorporated in the flattening function.

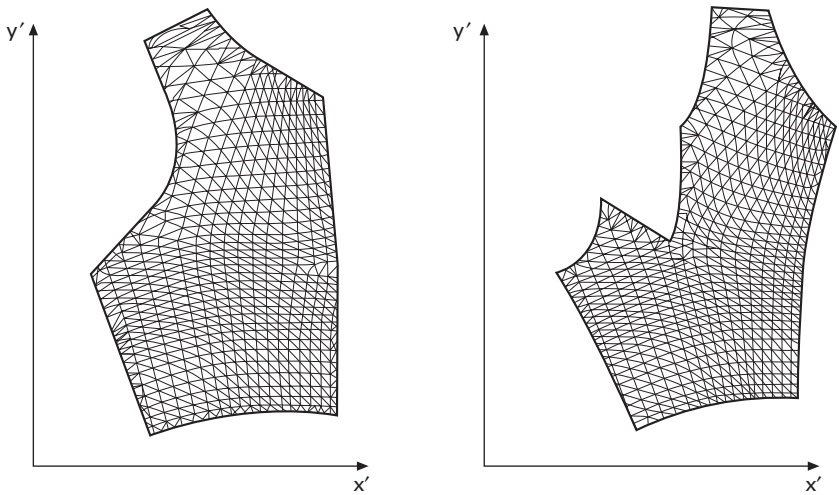
Figure 6.8(a) and (b) depicts the two flattening cases. Because the dart has been sited in the bust area which displays a high level of elliptical



(a) Panel triangulation (b) Panel RGB rendering

6.7 Single-dart panel display relative to underlying body.

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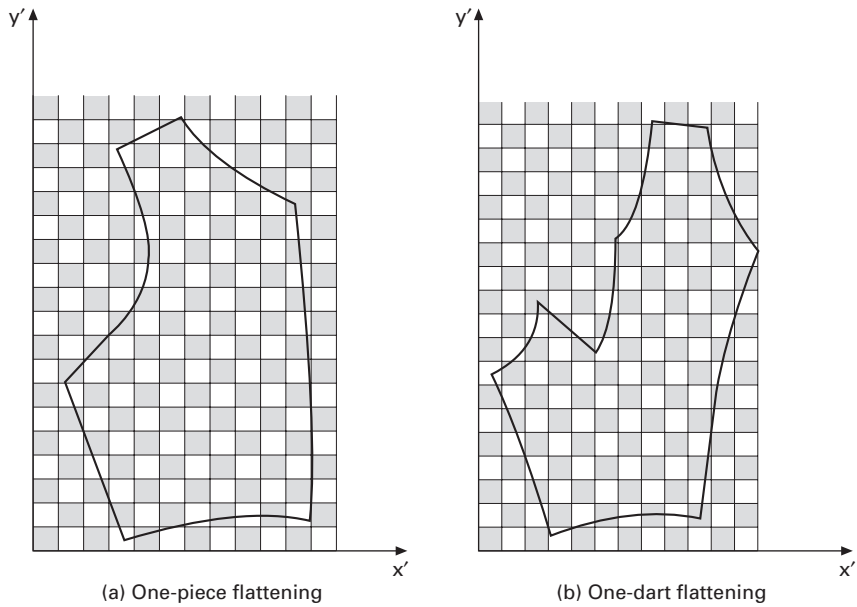
(a) One-piece flattening (b) One-dart flattening

6.8 Initial 2D pattern triangulation.

curvature, the flattening process has caused the 2D pattern to splay apart in this region. Note that the flattening plane (x',y') should be distinguished from the 2D parametric (i, j) plane. The presence of the dart will inevitably reduce the distortion that is required to make the 2D pattern assume the 3D shape of the panel compared with the one-piece pattern. In addition, it is possible to detail the precise distortion profile over the complete 2D pattern interior for each case. This is because the 2D pattern does not simply exist as a 2D outline but as a full mapping of all the interior triangle nodes. So it is possible to define the individual distortion that must be applied to each 2D pattern triangle in order for it to take up the shape of the equivalent triangle in the 3D panel. In fact, when seeking optimal patterns, a wide range of parameters can be considered: covering material properties; number, size and location of darts/gussets; and what are the acceptable tensile and shear distortions.

A complete 2D pattern specification for real garments does not simply consist of the 2D outline but there should additionally be some location of the outline with reference to the texture. This is incorporated into the design process by provision of an overlay interface where the fabric texture is initially displayed as in Fig. 6.9(a) and (b). The 2D outline of the pattern is then presented with the functionality of enabling the operator to translate or rotate the outline. Once the pattern location has been established there is then a link defined between 2D pattern positions of nodes and the equivalent 3D positions that are fixed relative to the underlying 3D body. The final result is that the RGB rendering of panels can be enhanced by producing a more accurate and realistic rendering of fabric texture as in Fig. 6.10(a) and (b).

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(a) One-piece flattening (b) One-dart flattening

6.9 Two-dimensional pattern overlay on fabric texture.

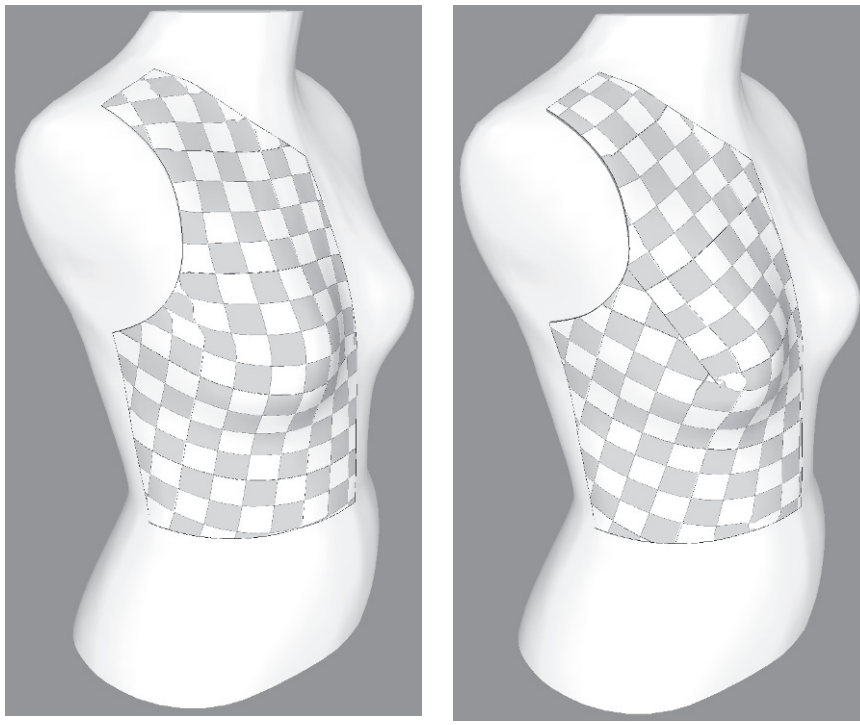
This rendering will embody all of the strains that are implicit in distorting the 2D pattern to assume the shape of the 3D panel. Hence, a more authentic basis can be provided for predicting the final appearance of a garment when a number of panels have been designed and assembled.

6.6 Full system implementation

In practice, such design entities described here can be assembled to form reasonably complex garment shapes. Although a single panel has been used for illustrative purposes, the same design process can be repeated over different areas of the underlying body. Indeed, there is no reason why panel coverage can not occur over the same area of the body but at different offsets. Hence, linings or undergarments can be designed. The panel detailed above was fixed at a constant 2 mm offset. However, a limited amount of offset variation can be accommodated around a panel boundary. This leads to a problem of interpreting the offset variation for the interior nodes generated by the bounding box grid described in Section 6.4.4 above. Other enhancements have been incorporated for re-creating effects such as padded panels. In this case, offset increases have been controlled by the medial distance associated with an interior node, i.e. the distance between the node and the closest point on the panel boundary.

It should be acknowledged that the approach proposed above is not appropriate for garments whose shape is significantly determined by the

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(a) One-piece flattening (b) One-dart flattening

6.10 Texture rendered panel on 3D body.

draping characteristics of the fabrics concerned. For such garments, the influence of gravity is predominant and the fabric essentially collides with the body instead of being distorted by it. In addition, the system will begin to perform erratically if large offsets are used. This is because concave regions of the human body will yield multiple solutions to the Newton–Raphson search technique described in Section 6.4.2 above.

It is the contention of the authors that the approach described above does represent a valid and efficient method for developing 3D designs for close-fitting garments and where bespoke high-value products are to be produced. In Fig. 6.11, a flak jacket is depicted that has been designed by the system and for which 2D patterns have been automatically generated which are sensitive to the material properties of the fabrics used.

6.7 Future work

6.7.1 Underlying body limitations

The design system described above cannot be applied to any shape of underlying body. The precise limitation can be described in terms of the curvature

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6.11 Example of flak jacket product.

variation of the surface. For a bi-parametric surface such as the human torso above, the principal curvatures can be calculated for any point on the surface.[9] The values provide maximum and minimum algebraic values. Of prime interest is the minimum value. If this is negative then the surface exhibits some concavity and will place a limit on the maximum offset that can be safely used. By calculating the reciprocal of this negative value, a radius of curvature can be determined which can be directly used to limit offset values by either (a) surveying the complete surface and setting a global limit; or; (b) calculating the curvature value interactively and applying a local limit. If these limitations are ignored and large offsets are used, then multiple solutions will be found for the constant offset processing described in Section 6.4.2 above and will result in poor quality curves being compiled which will not be comparable with the smoother curves observed during the interactive design stage.

6.7.2 Underlying body topology

As referred to above, the topology of the underlying surface can be loosely described as a distorted cylinder. This is to facilitate the dual representation

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of points in parametric (i,j,k) space and Cartesian (x,y,z) space so that mouse movement can be interpreted as (i, j) coordinates with mouse button presses controlling the k value. Due to the relative nature of the mouse device, it can be used to develop a flexible interface. For instance, with the configuration described above there will be a limit when the user moves the mouse to the right beyond a position equivalent to the $j = 73$ location. This can be overcome by detecting such mouse movement and forcing the mouse parameter location to be reset from 73.0 to 1.0. In this way, further right movement of the mouse will cause the 3D cursor on the body to seamlessly move across the boundary. The same resetting process can be implemented when the mouse is moved to the left beyond the $j = 1.0$ limit.

If not handled correctly, problems will occur during the search process when attempting to determine the internal points for a piecewise-linear step that crosses the $j = 73.0$ boundary for instance. Such discontinuities can be detected and modifications made to the j values. With this type of flexibility, it is possible to provide seamless operation with no apparent limitation to mouse movement or the definition of geometric entities across the $j = 73.0$ boundary.

It is the authors' contention that the same seamless operation can be implemented for allowing movement between different bi-parametric regions. For instance, arms and legs can be represented in this way. The seamless movement described above can be extended to provide smooth progression from the torso to an arm thus allowing the design of panels that span different bi-parametric regions, e.g. a sleeve.

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7

Computerised pattern making in garment production

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7.1 Introduction

The creation of a garment prototype begins with development of a conceptual design, next a basic block pattern is selected and modified to achieve the desired style. A sample is cut and sewn together, an iterative procedure is run until the fit is approved and, once this is completed, the basic pattern is graded to produce a size range for production. This entire process is time consuming when working in a fast fashion global production environment. Technology today has seen pattern making tools that have been carefully developed to perform repetitive tasks quickly. Product style and speed to market play a vital role in a rapidly changing clothing industry. The clothing industry is the most skilled labour-dependent industry and any cost saving through new computer-aided design (CAD) technologies has become a requirement in gaining a competitive advantage. Speeding up the product development process will undoubtedly produce a higher return on investment. While manufacturers offer unlimited designs, the problem is how to bring products to market and achieve up-to-date information that is easily obtainable. Today, CAD technology has enabled clothing design, pattern construction and product development to be integrated into a more continuous process.

7.2 Principles of pattern making

Pattern making represents the development of two-dimensional (2D) component parts created for a styled garment. It is a craft that has evolved into a skilled technical process. Two-dimensional patterns, once created, are used as a template for cutting fabric, which when sewn together forms a 3D garment. The development of 2D patterns is the technique known as pattern construction or pattern cutting.

A block pattern is a foundation pattern that reflects the size, shape and posture of the human figure without the inclusion of style features. The block is constructed according to the measurements for the base or sample

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size within the product range. A newly constructed block has to be tested by making the block garment. If necessary, the pattern has to be revised as measurements alone do not reflect the total body shape. The advantage of using block patterns is that they are a permanent record of correct fit. Once the block is perfected this can then be digitised into the CAD system. The advantage of designing patterns via the Pattern Design System (PDS) CAD pattern media is that it enables the intelligent block to include all the grades required for all sizes. This means when a new style is created from the intelligent CAD block all sizes are also generated, thus speeding up the pattern design grading process. Consequently, pattern construction and pattern grading are completed in one operation.

There are four basic techniques of constructing a pattern shape: modelling, drafting, suppressing and flaring. For those skilled in modelling or draping on a workroom stand, a block pattern can be created by this method; the fabric is cut then flattened and traced around the shape into the pattern CAD system (Fig. 7.1). Drafting is a traditional method found in many books published on pattern construction. Often no explanation is given as to where certain body measurements are extracted from and used. Garment shaping by suppression is the reduction of surplus fabric to obtain a closer fit using darts, seams, pleats or gathers. This controls the shape of the garment according to the contours of the body. The technique of flaring shapes the pattern by gradually increasing the fullness to the lower edge of a pattern this process is also known as cutting and spreading.



7.1 Gerber Silhouette.

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7.3 Garment balance

Garment balance is an important factor within pattern development; a well-balanced garment hangs in the correct relationship with the wearer's size, contour and posture. The posture of the body is determined by the natural stance. This can be influenced by both size and age. Those with a fuller figure in front tend to stand more upright to retain their balance. The correct balance of a garment is where the hemline is parallel to the ground and the centre back and centre front lines and side seams are perpendicular to the ground. There are two main areas that control the balance of a garment. For garments worn from the upper body, the area is from the shoulders to chest level. From the lower body, it is from the waist to hip level. Faults that appear below these control areas are often caused by faults within these areas, for example an uneven hem or a crooked side seam. Two- and three-dimensional body-scanning systems plus the comparison of body measurements can be very useful in assessing the figure shape in relation to garment balance.

7.4 Size charts

Body measurements are a prerequisite to pattern construction. The size and fit of a garment depends upon the accuracy. At present, we are in the transition between traditional manual measuring by tape measure and computerised body scanning or using photographic systems. Manual measuring requires a high degree of skill and is time consuming. The techniques of body scanning are constantly improving and will supersede manual methods in the future. Whichever method is used, the first consideration is to decide which measurements are required. From the data collected, the development of size charts for pattern grading and garment production begins. Size chart formulation begins with the division of average body measurements artificially into categories to form a range of sizes. These average body measurements are obtained from surveys of body measurements. Each size is given a code, e.g. 10–12–14–16, or labelled small, medium, and large. There are five stages in developing size charts for garments, as described below.

1. Obtaining body measurements.
2. Statistically analysing measurements.
3. Adding ease allowances.
4. Formulating the size charts.
5. Fitting trials to test size charts.

7.5 Pattern grading

Pattern grading is the process of producing patterns of different sizes from a master pattern according to a specified size chart. The amount that the pattern

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increases or decreases, and the direction of these size changes, have to be determined. At the same time, the correct proportions of the garment have to be maintained without distorting the style features. A 'grading increment' is the difference in measurement between two sizes, either in a size chart or at a specific point on a pattern. 'Grade points' are positioned at the cardinal points of a pattern where the measurement to another size takes place. This movement is in an *X* (horizontal) and *Y* (vertical) direction and is referenced on the CAD digitiser as a vector co-ordinate. The *X* axis usually represents the straight warp grain of the fabric and is generally used as the 'grade reference line'.

'Grade rules' record each movement of a point in both *X* and *Y* and are numbered relevant to the pattern grade point. The grade rules are listed in a grade rule table. The same rules can be assigned to any point of any other pattern piece within the same size range. Once a grade point is assigned to a point on the pattern, the computer automatically redraws the shape of the piece by connecting the grade points. Pattern input is usually via a digitiser using a cursor to trace the pattern and input information into the CAD system. The position of the cross hairs on the cursor registers the *X* and *Y* co-ordinates on the table top wire grid generating the pattern vector shape. Scanning is also another method of capturing the pattern shape, Gerber Technology, USA have recently introduced AccuScan, an automated, high-speed pattern digitising system that eliminates the need to digitise patterns manually. This new scanning technology digitises multiple patterns simultaneously and outputs AccuMark pattern pieces. Gerber states that AccuScan is typically 20–50% faster than manual digitising, depending on the complexity of the pieces being digitised. However, previously developed pattern scanners were deemed not as accurate as digitising.

7.6 Computerised made-to-measure systems

Among the software solutions offered by CAD vendors, a resurgence in made-to measure (MTM) allows manufacturers and retailers to develop into the rapidly growing area of mass customisation. With the new technologies developed to simplify the customisation of a garment it is now possible to automate garment development through to the point of manufacture. This gives the ability to manufacture single garments at mass production speeds and avoids the high cost usually associated with single-garment production. MTM software is designed to integrate with existing CAD modules, allowing quick and easy entry of customer details, body measurements and customer orders. Computerised MTM pattern drafting software is implemented by programming the traditional tailor's code methods or applying alterations to standard graded patterns. The integration of pattern design software, plotters, cutters and production schedules are all embraced.

Before implementing computerised pattern alterations for figuration on a

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commercial CAD system, a large database with reference to the graded patterns, the alteration movements and relevant information needs to be generated. There are many difficulties in creating grade rules and alteration movements, especially for bust suppression and the shaped sleeve, in order to obtain sophisticated patterns with a good fit for MTM clothing. Most major CAD vendors have developed solutions to ease the production of customised garments. A growing number of apparel manufacturers – from MTM jeans, swimwear, wet suits, and uniforms besides the obvious tailored suits and shirts – are now using this technology.

With the advent of new technologies the interface of computer CAD software now enables patterns to be created in a digital format. CAD vendors with this developing technology bring a more structured and systematic approach to pattern cutting and garment construction processes. This removes the time-consuming tasks of cutting card patterns, planning and drawing markers by hand and the duplication of hand-written instructions. Computer technology has enabled the clothing design, pattern construction and product development to be integrated into a more continuous process.

Pattern construction is part of the garment design and product development process. The pattern can also be considered as a foundation for garment production yet the complexities of developing and grading a pattern are often underestimated. To construct patterns by utilising the pattern CAD media requires two main skills: (a) knowledge of pattern construction and (b) the ability to operate the CAD program; prerequisites for skilled pattern technologists are to be both mathematical and creative.

7.7 Main technological advances in pattern making

The clothing industry has changed profoundly in recent years. Globalisation and increased speeds of information transfer and communication have stimulated competition. While manufacturers offer unlimited designs, the problem is how to bring products to the market quickly and achieve up-to-date information that is easily obtainable. CAD systems are now the essential tools required to integrate and achieve success, taking the role of 'configurator' between manufacture and retail. Utilising a full range of electronic tools, from the Internet to the new powerful CAD systems, can deliver clothing at relatively short cycles.

Developments within CAD for fashion, clothing and visualisation have been realised in the development of 3D software. Offering the designer a virtual prototyping system has been an active research area for many years; however, despite being applied through other commercial industries, its development for use within the clothing industry has met many research challenges. However, by presenting recent developments within this virtual environment the 3D picture becomes much clearer.

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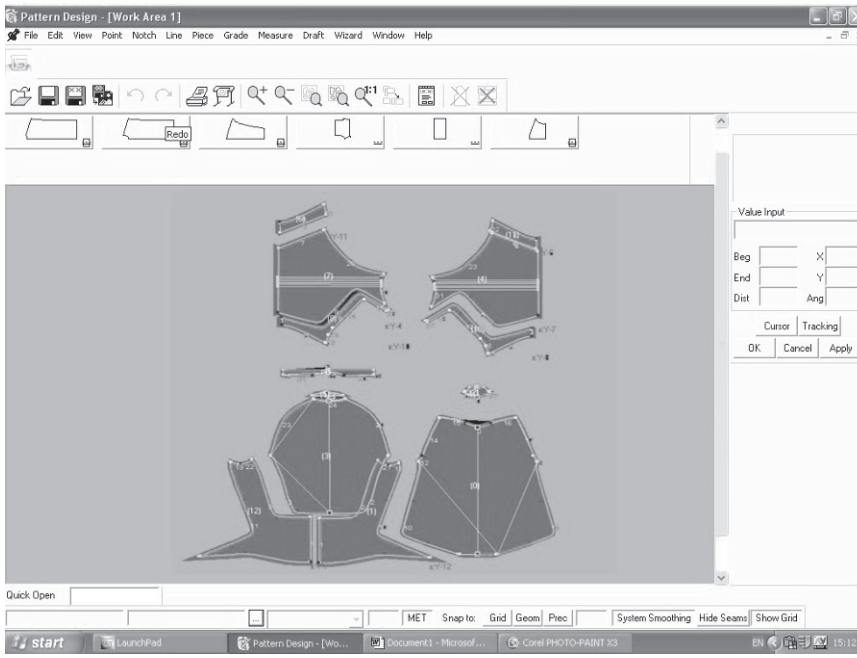
In relation to pattern design, the ability to move from 2D to 3D is perhaps the area of most interest. The creation of 2D pattern shapes that can be wrapped around a virtual mannequin fits nicely within the 2D CAD pattern development application used within the industry. The ability to move on from this point of development seems likely to be the most acceptable way forward for the designer and pattern technologist.

7.7.1 Gerber Technology

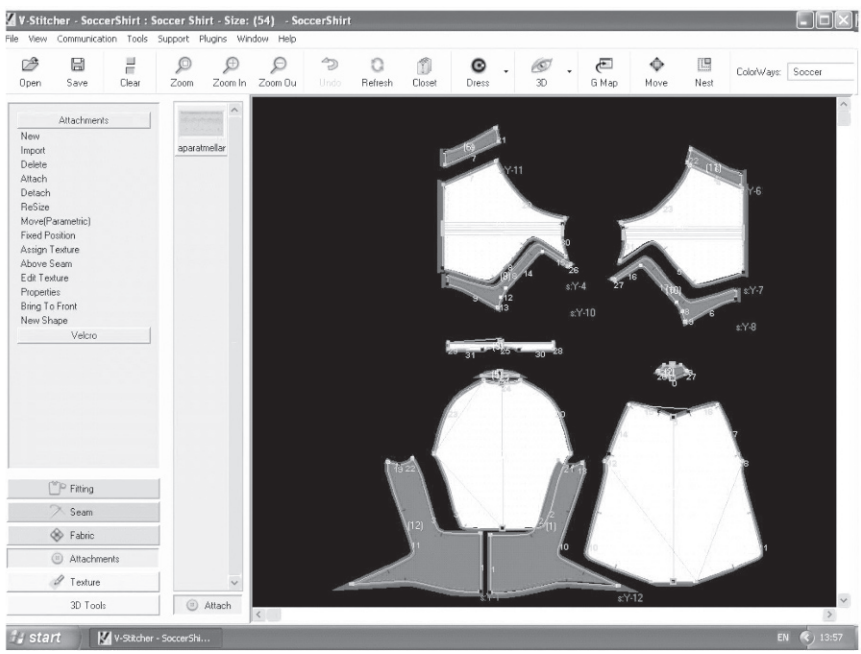
Gerber Technology now offers commercially 'V Stitcher', a virtual garment draping system, developed by Browzwear and now fully integrated into Gerber's 2D CAD system; V Stitcher specialises in real-time 3D representation of clothing products, based on a personalised avatar (a virtual mannequin). This technology enables pattern technologists to view 2D garments assembled and draped on an avatar. The 3D viewer is a true to life adjustable, representation of the human body offering parametrically adjustable body parts. These new developments possess CAD capabilities such as moving and dragging points and curves which provide a user-friendly interface. The avatar enables customisation through a wide variety of parameters for alteration. The virtual body can be modified for a wide variety of human body shapes, hair colour and style can be changed, also shoulder slope and posture. A selection of male, female and children's avatars can be developed to address a specific company's size charts, or personalised body measurements entered manually or via a body scanner. Two-dimensional pattern input from Gerber's AccuMark PDS software allows pattern models to be established; once imported each pattern line segment can be associated and virtually sewn together. This process requires a thorough understanding of garment sewing procedures and is carried out with the seam allowances removed from the 2D pattern.

The avatars can be replicated exactly to a given size specification, both the viewing and lighting angles of images are user defined, and the horizontal and vertical cross-sections of the mannequin can be viewed offering the pattern technologist the ability to verify fit and ease allowance. Modifications in either 2D mode or 3D mode take immediate effect with results displayed. A cloth physical properties module within V Stitcher has the capabilities to store, change and simulate to enhance the virtual model. Mechanical properties such as stretch, shear, weight and bending resistance can be defined, applied and stored within the fabric database. The system also allows integration of fabric images from Artworks, another of the family of software solutions offered by Gerber Technology, virtual fabric swatches can be 'dragged and dropped' onto the virtual garment, and stitch types, buttons and trims can be changed. Current 3D software provides the pattern technologist and designer with a toolset to review the design and construction of their garments (Figs 7.2 to 7.6).

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7.2 Gerber PDS patterns.

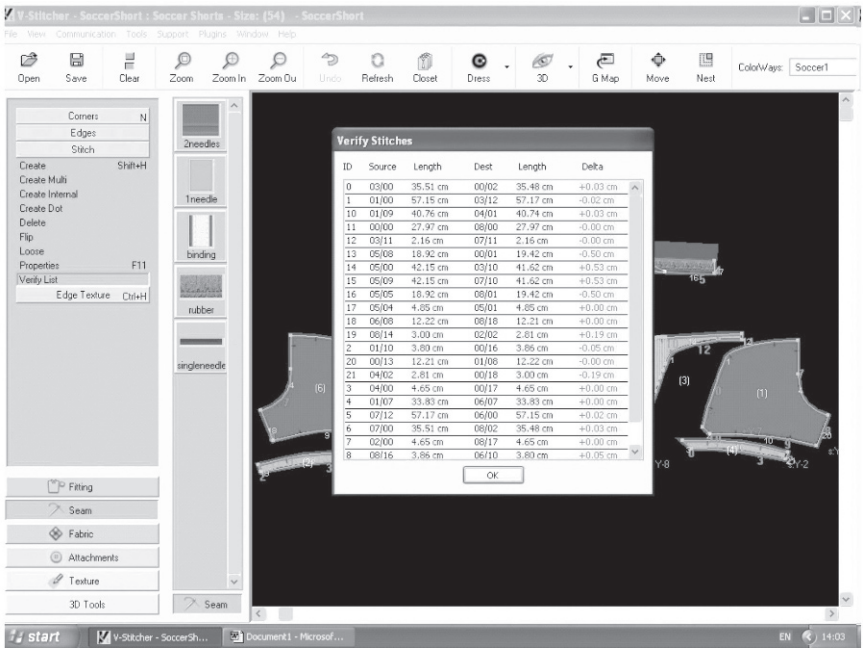


7.3 Gerber PDS patterns with fabric texture.

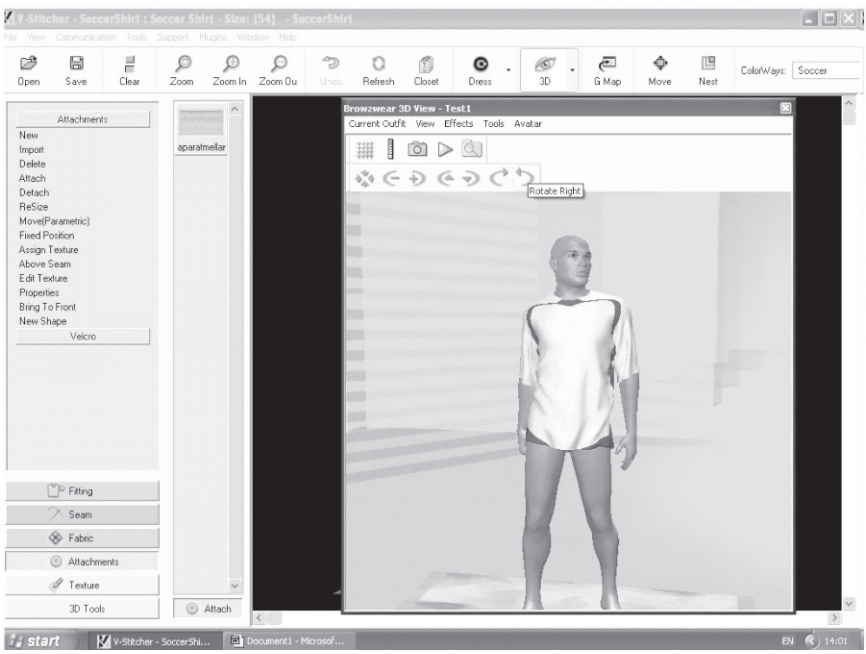
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7.4 PDS patterns of virtual sewing segments garment.

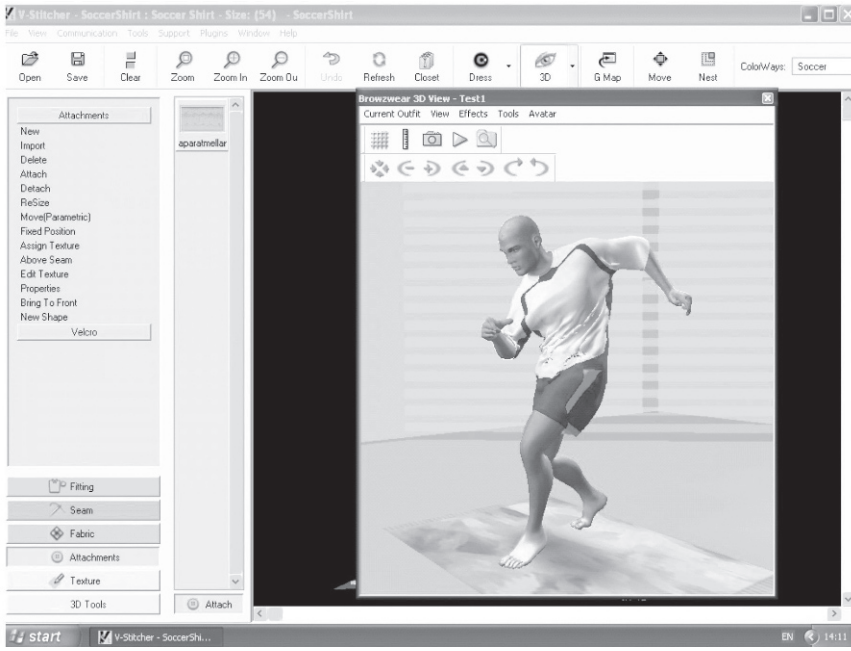


7.5 Browzwear virtual parametric garment.

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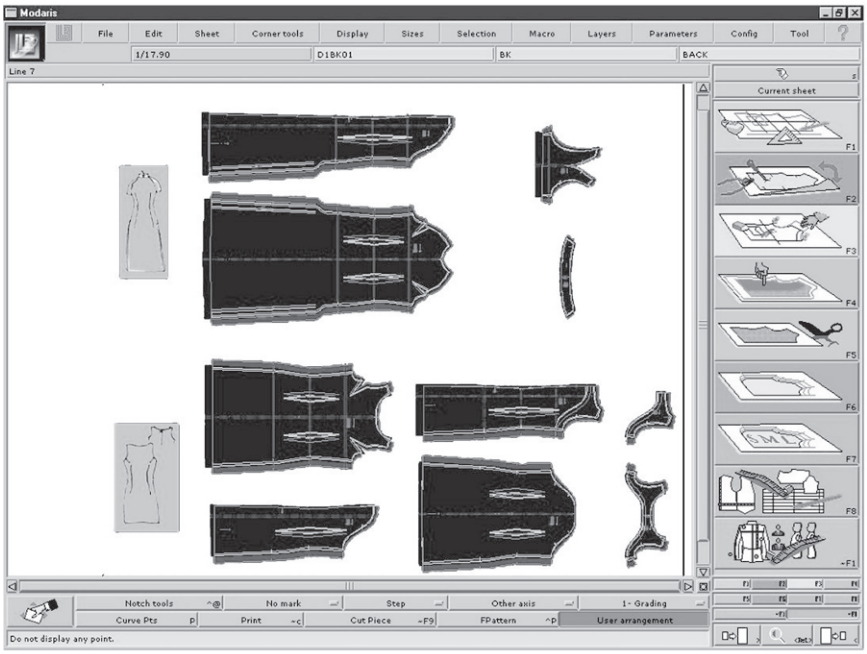
7.6 Browzwear virtual action pose.

7.7.2 Lectra Systèmes

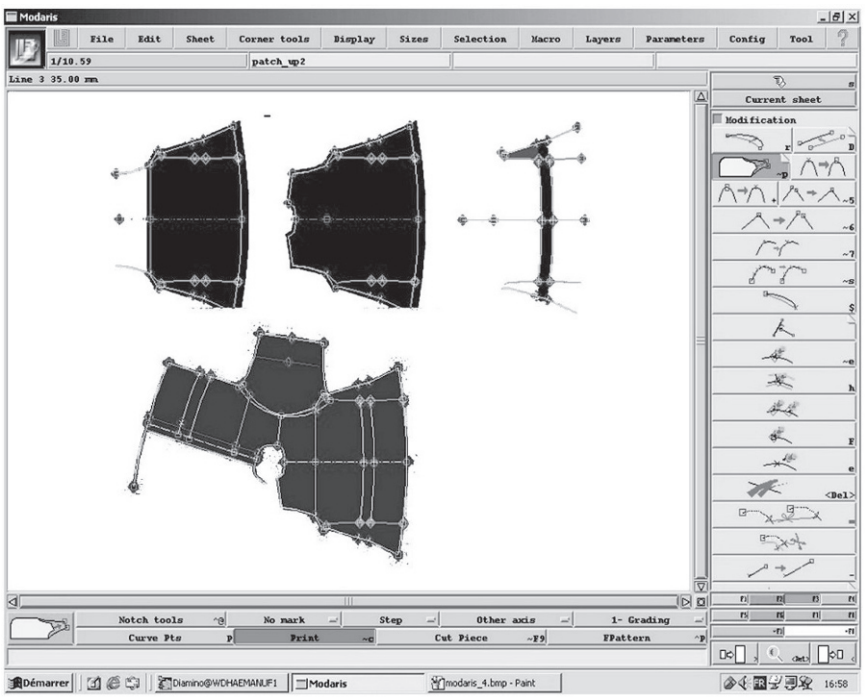
Lectra Systèmes has expanded its organisation to embrace all areas of CAD/CAM (computer-aided manufacturing). Lectra has been involved with the world of fashion for over 30 years. The expertise gained gives Lectra solutions a unique business dimension. They focus on the developments of Internet and Intranet, and virtual reality technologies are areas given high priority; the aim of these developments is to improve their products through brand building and increase sales with leading technologies. These developments will allow Lectra to incorporate their pattern module solutions and to offer commercially four key components: E-Design, E-Manufacturing, E-Sales and Lectra on-line. By maximising the potential of these technologies it may become possible to view an entire garment collection on a virtual reality catwalk.

CAD vendors with this developing technology bring a more structured and systematic approach to the pattern cutting and garment construction processes. At this stage of development, the 3D tools require improvement if they are to fulfil their promise and acceptability. Modaris 3D Fit, Lectra's 3D virtual prototyping solution associates 2D patterns, fabric information and 3D virtual models. This innovative solution, which Lectra states constitutes a major CAD breakthrough, enables simulation and validation of styles, fabrics, motifs and colour ranges; it allows pattern designers to check garment fit in various fabrics and sizes (Figs 7.7 to 7.10).

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7.7 Lectra Modaris PDS.



7.8 Lectra Modaris virtual sewing segments.

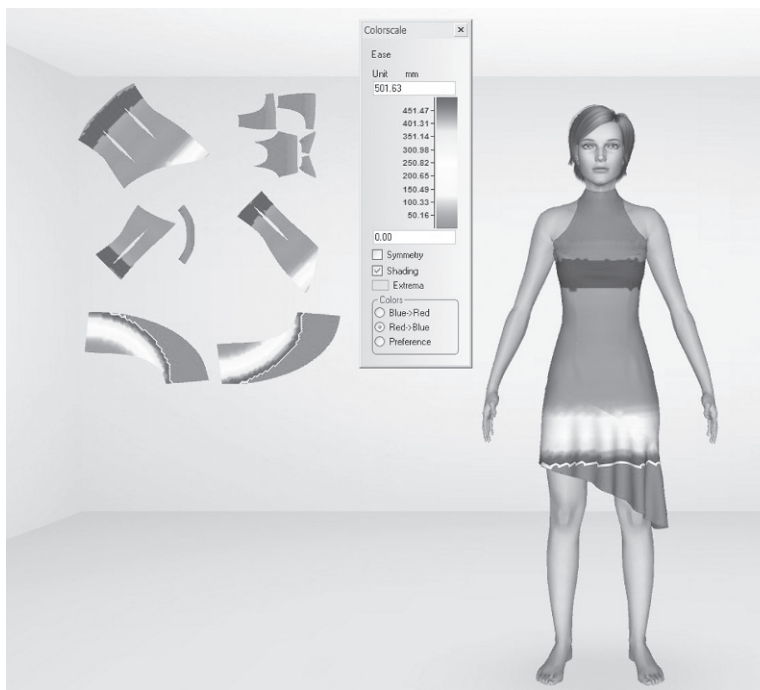
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7.9 Lectra virtual garment colourways.



7.10 Lectra virtual model fit-control ease.

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7.8 Material utilisation

Within the PDS system, it is also possible to generate automatically a costing marker which acts as a good basis for estimating fabric costs, given that around 50% of garment cost is associated with fabrics used. The main selling point of computerised pattern design, grading and marker making systems has always been the savings in fabric, achieving a high percentage of material utilisation. Today's CAD systems offer pattern design and grading functions to various degrees of sophistication and speed. There are two methods of making markers within most systems: interactive and automatic. For either method used, data relating to the marker are created in the model file. The file contains information such as the style name, number of graded sizes required, material width, blocking (setting an allowance around the piece perimeter for checked or striped fabrics) or buffering allowances (small cutting allowances), and if required flip and rotation restrictions. The interactive method relies on the user positioning the required pattern pieces over an image that represents the fabric on screen. The pieces to be placed are displayed in a matrix menu either individually or in tabular form. Each size can be viewed in a different colour, in outline or as a filled block. Pieces can be brought into the marker and placed accordingly and can be automatically positioned to the edge of the cloth or the next pattern piece, taking into account any blocking or buffering allowances. The production of the most efficient markers depends on the ability and spatial awareness of the technician.

Fabric widths can be changed to accommodate variations in fabrics supplied: if a marker has been produced and saved for a similar garment, it can be retrieved and displayed on screen for guidance. Alternatively, the marker plan can be copied. Engineering the pattern within the marker-making module is also possible to maximise fabric utilisation. The pattern splits can be vertical, horizontal or at at any specified angle, seam allowances can be automatically added to the modified piece. Examples of pattern engineering may be found on under-collar or facing pieces, generally where the seams are not visible on the outer garment. The length of fabric used and the percentage efficiency are monitored and displayed on screen as each piece is placed. A target efficiency can be preset to act as a guide to achieving the targeted percentage utilisation.

7.9 Applications/developments within computer-aided apparel systems

With the introduction of the above-mentioned CAD technologies, the quality of fabric spreading and automatic cutting has vastly improved to meet standards set. Cut-order planning systems are now capable of scanning cloth inventories and making use of small fabric rolls. Advances in automation and the

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development of automatic fabric-spreading machines mean that fabric rolls can now be loaded and threaded automatically. Using carousels that can hold ten or more fabric rolls allows for automatic uploading of material in the sequence required for the particular order placed. Fabric fault management, which is now also automated, has a great influence on the speed of spreading and cutting fabric: defects, damages and width variations restrict material utilisation, resulting in sub-standard garments. Gerber, Lectra and Bulmer have all developed the new generation of CAD/CAM integrating with the previously mentioned area of CAD.

7.10 Future trends

Product data management (PDM) software is a CAD tool that aims to reduce product development time, increase quality and improve communications between manufacturer and clothing retailers. Its function is to organise information in the product-development phase, to ensure technical specifications are followed to the last detail into the production phase of the garments. More specifically, PDM/product lifecycle management (PLM) systems contain information about patterns, garment construction, costs, quality and measurement specifications. New PDM/PLM systems are now Web-enabled, allowing the major CAD vendors' products to be Internet-, Intranet- and Extranet-enabled. The ability to transfer/share reliable information and ease of communication is of the utmost importance.

Three-dimensional visual merchandising is the new medium promoted by major CAD vendors offering the ability to simulate apparel collections quickly in any virtual 3D retail environment. The ability to create and control the retail environment – defining store layout, selected garments, style, colour, assortment and retail space – offers the ultimate assortment planning 3D visual merchandising system for apparel brands and retailers. This is made possible by a powerful database encompassing a catalogue of 3D fixtures, dressed mannequins and custom objects importable from 2D CAD media. The ability to visualise mix and match garments enables the e-retailer to increase sales on-line.

The success achieved by other industries in Internet e-commerce is beginning to gather momentum throughout the apparel industry, with the continued developments in visualisation technologies along with the ability to use 3D scanning data constantly improving the representation of garments on-line. This means that consumers from the comfort of their own homes, will be able to select a garment, use the data from the 3D body scan to try it on their own digital model, view around 360°, select the size that fits best or have the garment altered to their own specific measurements for a customised fit. One major problem with virtual fit technology is the ability to predict size and fit accurately. Currently, it may be seen as a marketing tool; however, this is a

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real beginning with obvious improvements pending as major CAD vendors continue to research and improve their products.

7.11 Sources of further information and advice

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- Lectra. http://www.Lectra.com
- Textile/Clothing Technology Corporation [TC]^2. http://www.techexchange.com

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Part II

Advances in apparel production

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8

Advances in apparel product development

D. TYLER, Manchester Metropolitan University, UK

8.1 Introduction

This chapter is concerned with new product development (NPD). There are numerous commercial pressures on companies involved in the supply of garments to consumers and they all come to a focus when considering the processes that link design with manufacturing and distribution. Globalisation has brought immense change to every aspect of the industry and this is the context for all the issues discussed here. The traditional process of NPD is described, together with indicators of the need for change. The major models of NPD are reviewed, identifying the concurrent product development approach as one that offers significant improvements. Tools and technologies relevant to the process are discussed, notably computer-aided design (CAD) development systems and product data management (PDM) software. The chapter goes on to consider the implementation of change, and shows that the role of the retailer (as supply chain leader) is crucial. Finally, discussion of fast fashion brings to a head the importance of restructuring the product development process to bring integration to internal systems and to supply chain management.

8.2 Industrial change

The past 25 years has seen a transformation in the way the clothing industry operates. In 1980, it was possible for all parties involved in the supply chain to attend meetings and to visit domestic spinning, weaving, knitting, dyeing/finishing and clothing assembly plants. Suppliers of commodities (buttons, zips, threads, etc.) were also close to hand. If there were problems, telephone conversations could be followed by site visits in order to resolve them. Numerous technology specialists could be called on to become personally involved, whether the expertise required was in fabric production, wet processing or garment assembly. By contrast, the industry is now globalised, with textile production, garment manufacture and commodity supply scattered

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in different countries, separated by language, culture, geography and time zones. Problem resolution is frequently done remotely because there are too many constraints preventing people from physically meeting.

The industry has responded by investing in technologies supporting communication. E-mail is routine, as is also the use of spreadsheets and CAD systems. Some suppliers have gone further and are equipped with PDM systems and other more sophisticated software tools. Video-conferencing is increasingly available and Intranet-based approaches to data handling have been adopted.

However, the biggest challenges are organisational in nature. Supply chains are made up of companies and people, and technologies are, at best, tools in the hands of users. It is not just the challenge of supplying goods to the specified quality, but of building in responsiveness and reducing lead times. This is because retail markets are characterised by volatility. Traditional approaches to forecasting consumer demand have become increasingly inaccurate with consequences of excessive cost. Reducing lead times, from placing orders to the stores receiving goods, is a major strategy for reducing risk. All supply chains are being asked to enhance responsiveness by looking critically at lead times and finding ways to speed up the delivery of goods.

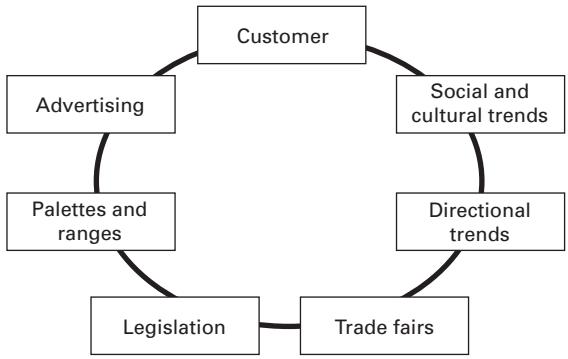
Undoubtedly, many of the technologies mentioned above have the ability to shorten lead times. CAD systems, for example, allow digitised pattern information to be e-mailed across the globe so that the supplier can grade the patterns and make markers to control cutting. Software ranging from spreadsheets to PDM systems handle a range of product information, including size chart data, quality requirements, care label instructions and the like. Proper use of these technologies ensures that the right information is present when and where it is needed, so lead times can be minimised.

It is unfortunate that many supply chain companies rarely get beyond these technological changes. This is not a reflection on their competence, but more a reflection on the supply chain as a whole. Organisational change that will deliver enhanced responsiveness needs wider participation and initiatives taken by companies acting alone will be perceived as ineffective because the measurable benefits are low. This chapter is concerned with organisational change affecting NPD, which is suggested to be the next critical area for achieving greater responsiveness in the supply of clothing products.

8.3 Process model for clothing product development

From a retail management perspective, the initiation of activity is the range plan. From a design and product development perspective, activity emerges as part of the cycle of ‘design influences’ (Fig. 8.1). The cycle includes:

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8.1 The design influences cycle.

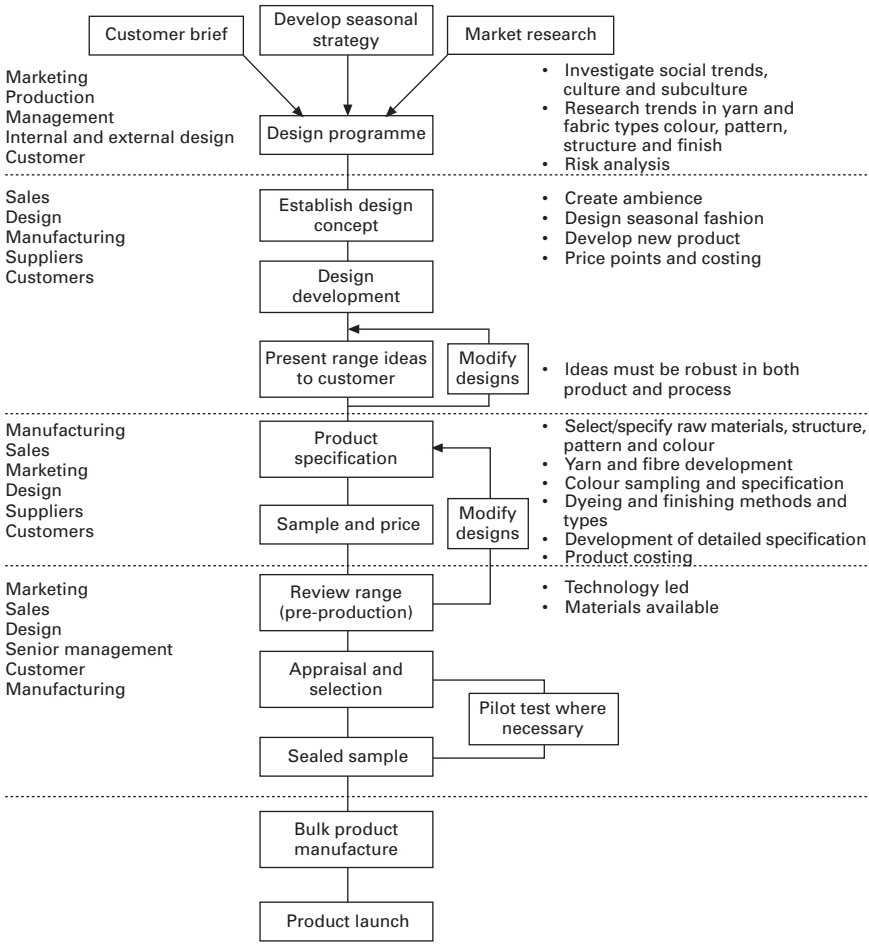
- analysis of social and cultural trends;
- utilisation of design trend information;
- visits to fabric fairs, fashion shows, etc. to stimulate ideas;
- attention to any legislative constraints;
- preparation of ranges for selection by retail buyers/selectors;
- product and range development over several months, with several sealed samples followed by bulk production (often commencing weeks before goods are due in the shops);
- advertising and marketing of the products, seeking to influence demand.

The design work leading up to the development of palettes and ranges, and the product development work culminating in approved (sealed) samples for bulk production is illustrated in Fig. 8.2.

Many large retailers build their product ranges around two seasons: spring/summer and autumn/winter. It is doubtful that any would insist that this approach is ideal. All seek to refresh their ranges within season. This is generally handled by the practice of 'phasing', whereby new products and ranges are introduced over shorter timescales. However, many of the decisions regarding the products to be phased in during the selling season are identified at the outset.

It appears, therefore, that the seasonality of the retailing product development timetable is still very strong and that major decisions regarding products and ranges continue to be decided very early on, before there is any demand-pull from consumers. As a consequence, the whole supply chain operates within this long product development cycle. For many years, trade fairs such as Premiere Vision have been perceived as triggers for initiating garment design activity (Forza and Vinelli, 1996). It is at this point of the design cycle that fabrics and colour palettes come into focus, although King (2007) reports that at least two major UK retail chains are making most of their colour management decisions before the shows. While companies vary in the details

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8.2 Process model, representative of many clothing products.

of their product development calendar, the majority are making decisions about their products well in advance of offering them for sale.

It has been suggested that the textiles and clothing sector has become locked into these long timescales and that this is against its long-term interests (Tyler *et al*., 2006). Calendars very easily become rigid because of trade events, and participants in the supply chain consider it advantageous to synchronise their activities with these events to maximise their own sales. The effect of this is to change the agenda for responsiveness in the supply chain: instead of time compression throughout product development, the overall timescale is fixed and decision points within the seasonal cycle are shifted towards the point of sale. This gives the impression that the main burden of enhancing responsiveness falls on suppliers. This is a misreading of the situation, and is discussed later in this chapter.

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An apparel supply chain benchmarking study (Anon., 1996/97) highlighted product development lead times as a weakness in the UK's international competitive position: 'One area we have highlighted is product availability – both from supplier to retailer and from retailer to consumer. While compared with overseas competitors UK manufacturers' production lead times were the shortest, this was counterbalanced by the fact that developing the product in the first place is not as effective as international competition.' This benchmarking study of the UK textiles and clothing sector revealed that product development was a major area for improvement. The findings showed that timescales are long, there is much wasted effort, and that communications between the different functions – design, production, marketing, sales – are poor. Watson (1997), who managed the study, estimated that, on average, only 30% of the products developed actually found their way into the store (with designs often being adapted or modified more than four times from first sample to final approval), revealing further some of the inefficiencies of the product development process, possibly as a result of these communication problems. Watson provided this statistical summary: 'the product development cycle in the UK currently takes on average 167 days, the manufacturing part of this is only 39 days, so the industry spends a lot of time deciding what to manufacture, and clearly, this is both a direct and indirect cost.' These figures are not so dissimilar to those obtained by other industries, where the manufacturing lead time is comparatively short in relation to the product development time. Product developers need to reflect on their own processes and consider whether their timescales are justified and whether they can themselves contribute to time compression. It should be pointed out that all personnel involved with NPD are very busy and have many deadlines to meet, so any thought of shortening the timescales is regarded as unrealistic. However, the point being made here is about *process*: it is not how hard people are working but what activities make up their working lives.

8.4 Models of new product development

There are three themes that consistently appear in literature related to product development success factors. These are summarised by Hart and Baker (1994).

1. Interdisciplinary inputs. It has always been recognised that different disciplines are needed in the process of NPD. Successes are typically linked with professionals from different disciplines actively collaborating.
2. Good quality information inputs. Whether it involves technical inputs from suppliers, or consumer-related information from marketing, all information sources must be accurate and timely.

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3. Short lead times. The ability to launch market-relevant products quickly can be translated into financial benefits. Nevertheless, there are also risks, and organisations wishing to beat their competitors on 'time-to-market' must manage the process carefully.

Consequently, NPD analysts have been stimulated to scrutinise models and procedures for how they handle these issues and how improvements can be made. A useful starting point for thinking about *process* is to consider different models of the NPD process, as identified by Saren (1984) and discussed by Hart and Baker (1994). Saren has five models in all, but the first three are particularly relevant to our interests here.

1. *Departmental-stage models*. This is the classic 'functional independence' approach, where each department or function has clearly identified objectives, and the 'product' is signed-off as it moves from one stage to the next. While appearing to be logically sound, it suffers from the presumption that product objectives can be achieved by a reductionist approach (i.e. the sum of the distinct objectives of each function).
2. *Activity-stage models*. The approach is product-focused (rather than influenced by functional boundaries) and the activities needed to develop the product are identified at an early stage. Resources are then made available to support those activities and achieve the desired outcome. Although an improvement over model 1, the approach has been criticised for continuing the 'pass the parcel' tradition because activities are still closely linked to functions within organisations. In many cases, including clothing product development, the distinction between models 1 and 2 is hard to discern.
3. *Decision-stage models*. The NPD process is represented as a series of staging points, where progress is evaluated and where decisions are made to continue or abandon the project. Activities in each stage are selected so that the point can be reached where a meaningful decision can be made at the end of that stage. A possible problem with this model is that the emphasis appears to be on the decision points, but what goes on in the intervals between decision points is just as important as having staged evaluations. Nevertheless, this model does provide an opportunity to break out of the departmental/functional framework and to develop team-based approaches to product development.

These models allow a broad comparison to be made between sequential approaches to NPD (represented by models 1 and 2) and concurrent approaches (represented by model 3). Comparisons and contrasts have frequently been made in other industrial sectors. Numerous industries in many countries have faced similar challenges to improve NPD processes. Sequential processes are deficient because product development decisions cannot be made without

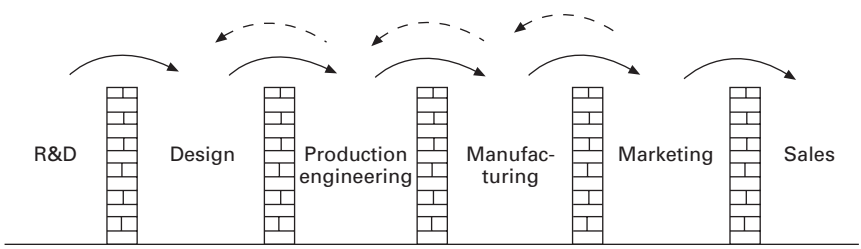
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reference to the end-product. Functional and activity boundaries are walls that inhibit vision. Decisions are often made that are non-optimal for subsequent functions or activities and they have to be re-made. For example, a specific design feature may be achieved by a particular assembly technique that can be completed satisfactorily by a sample machinist, but in manufacture, the assembly technique may not be commercial because it is too slow, or because it leads to excessive problems of quality failure. The assembly technique needs to be appraised by garment technologists and manufacturing specialists and their work needs to inform the design process.

This sequential approach is often described as each department 'tossing the product over the wall' to the next in line, with communication being portrayed as linear (as in Fig. 8.3). The approach has an embedded problem: the adoption of functional independence. This is because getting the product right for the market actually requires functional interdependence. Later-stage functions either do the best they can with the product as they have received it (which means that compromises are inevitable) or they return the product to the relevant function with a request for further design/development work (which means time delays and additional costs).

By contrast, the concurrent product development process can be likened to a relay race where a baton (the product) is carried by a succession of runners from the start (design concept) to the finish (in the hands of a satisfied consumer) in the shortest possible time. Transfer of the baton from one runner to the next must be handled well so there are no errors and delays. Relay runners must each make their distinctive contribution, but the transfer of the baton is critical to success, and this requires common goals, coordination, communication and concurrent activity.

The need for better quality and shorter product development lead times is widely acknowledged. There has been a growing realisation that the concurrent product development approach (model 3) offers an effective way to achieve these objectives and it is a recognised strategy for enhancing competitiveness and for overcoming the problems emerging from sequential routes for NPD (Bhamra *et al.*, 1998). Figure 8.2 has, on the left-hand side, a listing of possible team members for each stage of the process. There are



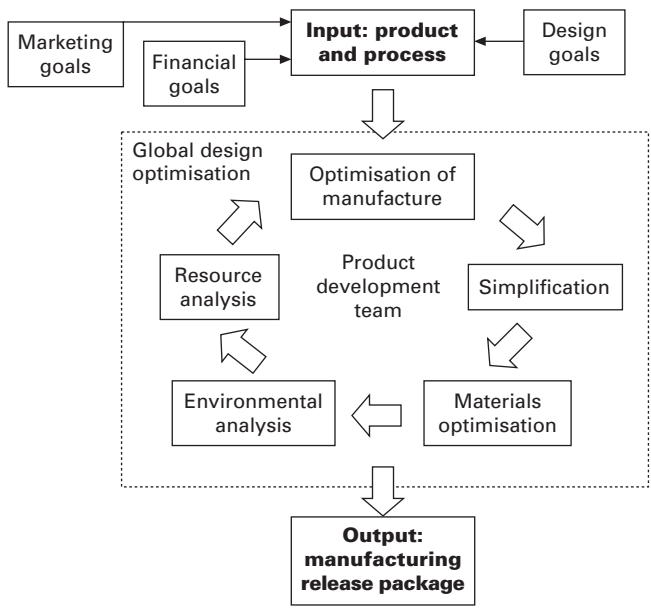
8.3 The sequential approach to NPD and the problems of reworking decisions made at earlier stages.

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different functions represented who become involved when they have a contribution to make. The team's role is to take the products through each stage in turn, ensuring that, after the decision points, the project can be handed on smoothly.

Figure 8.4 provides an overview of how product development might operate using the principle of concurrency (Tyler, 2008). The starting point is a proposal for a new product (and associated manufacturing processes) from a new products team. This feeds into a global design optimisation procedure.

- Stage 1 is *Optimisation of manufacture*. Product and process plans are scrutinised carefully to achieve integration, and the output is a product design plan.
- Stage 2 is *Simplification*, where the product design plan is analysed in terms of its target customers and over-designed features are removed. At this stage, there may be simplification to achieve a retail customer's price point.
- Stage 3 is *Materials optimisation*. This looks at the design plan in terms of materials selection, tolerances, performance in use and so on. Alternative materials are considered and evaluated on performance and cost.
- Stage 4 is the *Environmental analysis*. The product design plan is considered in the light of the environmental policies of both company and customer. Abridged life-cycle analyses are carried out to address



8.4 Overview of the concurrent product development approach.

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issues of waste in manufacture and in the supply chain. Alternative technologies are explored to improve the environmental profile of the product.
- Stage 5 is the *Resource analysis*. This looks at the resources required and available, and produces a resource-dependent design plan.

The global design optimisation loop is entered again at Stage 1 and continues until a satisfactory outcome is reached.

Technologists have a vital role to play in every stage of this product development model. Sometimes, the main channels of communication are with production people (as in the optimisation of manufacture and resource analysis); at other times, the focus is on the design aspects of the product (as in simplification and materials optimisation). The environmental analysis promotes communication throughout the supply chain and, here also, there are opportunities for technologists to contribute.

The major challenge with this approach is that companies are not used to a structured, managed process and there are often numerous pressures to make decisions pragmatically. Furthermore, people are not used to working in multi-disciplinary project teams, especially if they involve different companies in the supply chain.

8.5 Product development tools and application areas

The global context for clothing supply has already been identified above, with the corresponding problem of reduced opportunity for co-located meetings. Tools for NPD are required not only for completing specific tasks, but also for supporting international communication. This is not such an issue with a sequential process, but it is very important where companies have adopted concurrent product development. Transparency of information is a desirable goal and appropriate tools will deliver it. As Gereffi (1999) points out, industrial upgrading is a continuous process that is moving centres of expertise away from sourcing countries towards suppliers. In many cases, the retail customer or brand owner has outsourced all technical work with patterns, retaining only the creative design function. In some cases, even design has moved offshore. In such a fluid situation, efficient and effective NPD communication must be a priority.

CAD software for pattern specification, grading and marker making has long been used in the industry, and it is difficult to regard these as other than indispensable. Digital information can be communicated easily and in ways that are compatible with globalised supply chains. Other software tools are used at the design stage, for forecasting, designing and collection planning. These are outlined in Cooklin (2006) but are mostly stand-alone tools that do

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not communicate outside the design office. Research seeking to integrate CAD technologies and to extend downstream to the manufacturing process is discussed by Istook (2000).

PDM systems are rather different: they are designed to ensure the accessibility of up-to-date information. Pre-globalisation, the need for data communication was often met by the use of customised spreadsheets. Companies would design pages for the different types of data and the format was simple to pass around. The problems come as the systems grow and as the volume of data expands. The number of sheets can get very large, and different customers may need to have different customised formats of spreadsheet, so the task of maintaining and updating the database becomes overwhelming. Companies struggle with several extant versions of the database and old information is not quickly removed from the system. Information flows in clothing supply chains do not have a good track record of working well (Popp, 2000). In summary, product development information is difficult to manage for the following reasons:

- information overload;
- incompatible formats (e.g. computer disks, paper documents, etc.);
- users in different functions have varying needs and skill levels;
- difficulties in updating all users quickly to the current version;
- different terms are used to define the same data.

PDM suppliers have identified the practical problems of traditional procedures as follows:

- limited standardisation;
- errors and duplication;
- lack of workflow tracking;
- inefficient processes;
- ineffective processes.

This is where PDM, particularly its web-based versions, offers to satisfy a real need. The aims of PDM are as described below.

- To control product data (standardised formats, up-to-date information, data security, movement of information).
- To integrate data across functions (avoidance of duplication, easy access to data entered by other functions, transparency).
- To ensure one extant version (all data held centrally, changes and updates made to master only, up-to-date information communicated to all terminals).
- To support process management (enhanced communication, documented product history including times for completing development stages).
- To reduce lead times (reduction of time spent administering the process, reduced errors and more ‘right-first-time’ activity, reduced delays waiting for information).

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The basic structure of a PDM system is to have a folder containing all the information relevant to any particular style. Some of this information will be links to standard data sets – such as size specifications, colour standards, quality standards, instructions on how to take measurements, finishing procedures and packaging procedures. The folder will have the ability to store images, to develop a costing for the product, to record all communications about that product and to document progress in product development and in manufacture. Instead of starting each new style with an empty folder, data entry can be minimised by copying a past similar style and editing the data that need alteration. This architecture makes PDM an ideal tool for use with the concurrent product development approach (Gascoigne, 1995).

As with all software systems, PDM software is continually being updated to give enhanced performance. Such facilities may include integrated e-mail, language translation for use in different countries, the ability to store video clips, libraries to support labelling and the incorporation of standard procedures for cutting, sewing, pressing, inspection and packaging. Users may have the option of customising their own forms for data viewing and reporting. Quality data and other test results can be entered to the database with exception reporting to management.

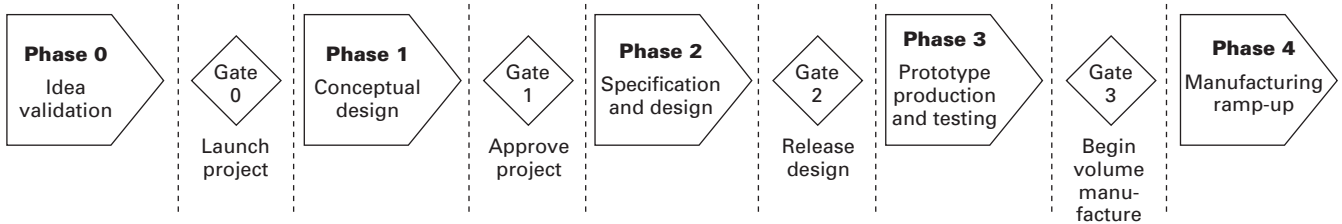
Concurrent product development approaches come with their own suite of tools. The most important relate to the decision gates (Fig. 8.5), following development activity to achieve agreed objectives. Another important tool is the product development cost model (enabling informed selection of projects using product cost/quality/development speed/development cost trade-offs). Numerous other formal methods have been developed, several of which are not feasible at all with sequential approaches to NPD. These include Design for Manufacture (DFM), Quality Function Deployment (QFD) and Design for Environment (DfE). DFM is a structured approach to ensure the product can be released to be manufactured without experiencing the costly technical and quality problems that occur during start-up. QFD is a structured approach to identifying the voice of the consumer and translating user needs into technical requirements. DfE brings an environmental emphasis to NPD based on designing good practice into the product rather than leaving it to the manufacturers to improve the environmental impact by cleaning up the manufacturing processes (so-called ‘end-of-pipe’ solutions). For more on DfE for clothing products, see Bhamra *et al*. (1998).

8.6 Product lifetime management (PLM)

The trend in information technology (IT) systems is towards integration of software modules. In particular, PDM software has the potential to be part of an even larger system that draws together all aspects of the activities of a company. Figure 8.6 illustrates the main modules:

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8.5 The gate review tool. This provides for a structured review process taking place at various key stages in the project. The gates represent a go/no-go decision to proceed to the next phase.

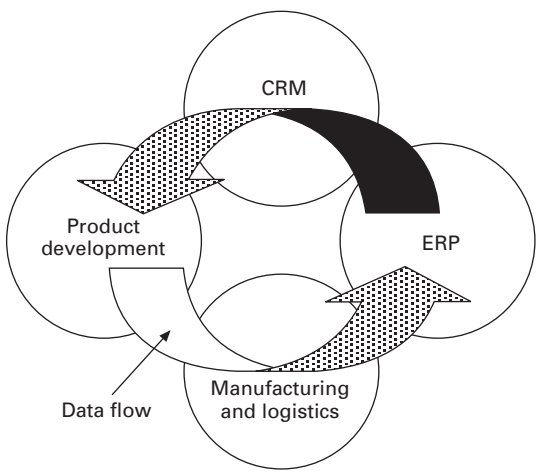
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- PDM (Product Data Management) for managing all data relating to product development and specification;
- PPM (Production Planning and Management) for production planning and management;
- ERP (Enterprise Resource Planning) for resource planning throughout the enterprise;
- CRM (Customer Relationship Management) for managing all links with customers.

All these modules can, in principle, read from and write to a common database. The vision is for an information system that does not create walls within the business that block information flows. Figure 8.6 shows a closed loop of information flow, with customer-related information feeding into the NPD process.

The significance of PLM for the product development process is that NPD activities must not take place without reference to the rest of the business. NPD occupies a significant proportion of the planned lead times for getting new products to market, and every step should be monitored and related to a critical path analysis. PLM provides this critical path tool. NPD data need to be accessed during manufacture to ensure conformance to quality standards, accurate labelling and packaging in accordance with customer requirements. Within PLM, visibility of data is integrated within the IT system and is not via a separate software tool. Manufacturing resources are considered within Stage 5 (Resource analysis) of the CPD model (Fig. 8.4) and data that are accessible at the product development stage greatly assist this aspect of the process. Customer-related data will include information relevant to future



8.6 The PLM concept, showing the context for handling NPD information.

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product development activities, and visibility of this data brings new opportunities to the attention of the NPD team.

As a concluding comment on tools, there are dangers in assuming that investment in tools is the key to developing the business. The main argument of this chapter is that organisational and people issues are actually much more important. Tools are necessary but not sufficient. They are a means to an end. Anecdotal evidence from industry is that when sophisticated software systems are acquired, users often only employ a small part of the functionality – not because this is all they need, but because they have not been trained beyond the basics and because the way the company is organised effectively restricts the full exploitation of the software systems. Organisational change and ongoing staff training should be considered concurrently with investment options.

8.7 Demand-led new product development

In the above discussion of the product development process, it was suggested that product developers need to reflect on their own processes and consider whether their timescales are justified and whether they can themselves contribute to time compression. In this section, we consider cases of how shorter timescales can be achieved, and then address NPD for fast fashion.

Colour management issues can contribute significantly to time delays. The term 'lab-dip' is frequently used to refer to a sample that has been dyed to match the standard supplied by the retail customer. These samples are costly to produce, and then they have to be transported by courier to a responsible person (often thousands of miles away) for appraisal. Retailers routinely refer to three, four or even five attempts to get the colour right. The difficulties are often associated with the way the standards are set in the first place, for which the retailer needs to take responsibility. The solutions, via engineered colour standards, are now well documented and are commercially available. A review of the issues is presented by Park (2007). The benefits of engineered colour standards are also documented: the time taken by one retailer to generate master standards has been reduced from 8 weeks to 2 weeks. In addition: 'Typical savings being achieved are a 30–50% reduction in the number of laboratory submissions from suppliers, with a similar reduction in the time required. It has been claimed by a major retailer that the savings in courier charges alone in 1 year paid for the capital investment in measuring and computer equipment' (Park, 2007, p. 5). This is a good example of where investment in IT will not deliver results without organisational change. The process of specifying colour by the retailer or brand owner needs to change if the technological solutions are to be achieved.

A listing of categories and component activities in the context of quick response (QR) clothing supply in Australia is provided by Perry and Sohal

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(2000). This gives a good indication of what suppliers can do to develop flexible working practices and enhanced responsiveness.

1. The fostering of an ongoing effective working relationship with local supply chain partners, which includes:
   - preference for local suppliers (unless not feasible);
   - the fostering of win/win supply chain partnerships as opposed to previous power relationships playing off suppliers;
   - promotion of supply chain partners' brands;
   - the receipt of on-time, in-full deliveries of products.
2. The establishment of procedures to ensure fast product turnaround in the distribution centre.
3. The implementation of technologies and systems for product-related information sharing with supply chain partners, including:
   - implementation of point-of-sale scanning;
   - the establishment of electronic links with suppliers;
   - the provision of weekly sales data to suppliers.
4. The implementation of a comprehensive QR organisation and education programme including, specifically:
   - the education of buyers to make buying decisions based on overall costs as opposed to price;
   - the education of shop-floor staff regarding individualised service;
   - the training of QR officers to work closely with supply chain partners.

The QR strategy has promoted a variety of mechanisms for rapid replenishment of stock items. All of these involve a careful coordination of the whole supply chain, because textiles and commodities cannot be produced at short notice, nor without attention to minimum batch sizes. In a simulation study of responsiveness, Al-Zubaidi and Tyler (2004) found that replenishment times of about 2 weeks are necessary to make a significant difference to the problems of stock-outs and excessive end-of-season inventories. This timescale cannot be achieved by tweaking supply-chain processes: the problem needs a radical process re-engineering exercise.

Warburton and Stratton (2002) discuss the concept of balanced sourcing, which retains sufficient domestic manufacturing to enable short lead times, appropriate for fashion markets, to be achieved. The practice of 'vendor-managed inventory' was explored, particularly in the USA, as a route for domestic manufacturing to compete with offshore suppliers. However, while some successes were reported, it became apparent that the cost advantages to be obtained from sourcing globally were too large to refuse. A recent analysis of business trends (Doyle *et al*., 2006) emphasises the importance of establishing strong relationships with suppliers, but adds a cautionary note:

> [The research] highlights the need to balance the intensive management inherent in a wholly responsive supply chain with the benefits of a two-

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> tiered approach to product and supplier management. The research suggests that it is not necessary to pursue a fully responsive supply chain to achieve both agility and product offer dynamism, but instead this can be addressed by identifying only those products and product categories that require rapid and frequent review, replenishment and refreshment. (p. 279)

The challenge many retailers face is that their internal systems require them to base most of their decisions on forecasting. Their timescales for product development are such that all the key decisions are made before the selling season for fashion products. They find it very difficult to make any significant changes to the NPD process model of Fig. 8.2. The consequence is that significant responsiveness cannot be introduced to the supply chain apart from fire-fighting (Tyler *et al*., 2006). The garment dye route has been developed by domestic suppliers to allow late-stage decisions on coloration, but the UK experience is that diminishing uptake has led to the closure of plants and the remaining capacity cannot handle surges in demand.

Those retailers that are developing a fast fashion offering have modified their NPD processes and have adopted a different internal organisation. Bruce and Daly (2006) identify three elements of a fast fashion strategy. These are:

- 'leagile' approach to supply chain management;
- a blend of long-standing and short-term relationships in the supply chain;
- the effective integration of internal functions and processes.

'Leagile' refers to a combination of *lean* and *agile* manufacturing principles and is a term relating to the supply chain. For further discussion of agile supply chains, see Christopher *et al*., (2004). It is the third of these elements that requires internal change in retail organisations. Bruce and Daly (2006; see p. 339) document three case studies of fashion companies, all of which have sought to achieve time compression.

> Common to each case was an integrated internal process whereby sourcing, buying, merchandising and design interfaced effectively to enable rapid decisions about the collection to be made. Technology was used in internal processes and the supply chain to convey the design of the collection, to enable changes to be made quickly and to speed up the design agreement and signing off process. In some cases, sourcing and management of suppliers was an integrated aspect of buying, as in the supermarket case. For the specialist fashion company, the technical team liaised closely with the suppliers, together with the buyers, to ensure that the design was interpreted correctly and to speed up the production time. For all three cases, merchandising was a separate activity, but was involved closely in the whole process of ensuring that product was presented in store quickly. (p. 339)

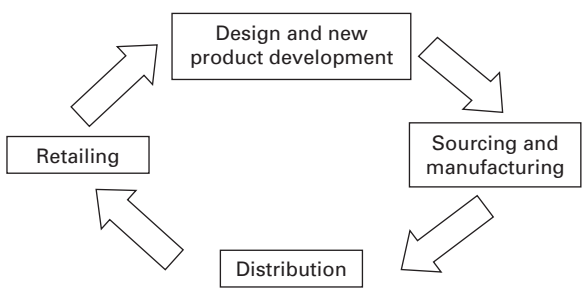
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Fast fashion has to abandon the two seasons a year planning structure because this always puts a heavy emphasis on forecasting. The planning window has to operate on much shorter timescales. The key processes are:

- focused market research (1 week);
- conceptual design, product development and specification (2 weeks);
- manufacturing (1 week);
- transportation (dependent on location of suppliers and distribution centre).

A review of academic research into fast fashion is given by Barnes and Lea-Greenwood (2007). They identify three models: the Zara model with 'short product life cycles and new product introduction every 3–4 weeks, achieved through fully integrated approach to supply chain'; the street fashion model with products that are 'constantly re-styled from small numbers of basic pre-existing designs. […] This model makes use of local suppliers […] and readily available fabrics, enabling a time from concept to delivery of only 2 weeks'; and the Pronto Moda model which is 'closely associated with the quick response model […] focusing on in-season orders and deliveries to supplement and refresh seasonal stock.' Of these models, the Zara model has attracted the most interest. Zara is the leading brand of the Spanish retail group Inditex SA. The company was formed in 1975 and has seen rapid growth of 30% annually. It is now a global retailer, reputed to be the third largest. Ferdows *et al*. (2004) have provided an overview of the company's operational procedures.

Most supply chain models are linear, documenting the forward movement of materials through various processes to become products in the hands of consumers. The models also document the reverse flow of information through the supply chain, triggering activity in accordance with the decisions of the retailer. However, these models do not work for fast fashion. For that, we need a closed-loop systems approach as illustrated in Fig. 8.7 (Ghemawat and Nueno, 2003). Retailing is not at one end of a chain, but is embedded within the process. In particular, retailing is actively involved in assessing



8.7 Systems model for fast fashion retailing.

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consumer demand. This is not just recorded via EPOS data (Electronic Point of Sale systems only document what consumers have purchased) but also involves collating the results of feedback from shoppers about their preferences and their perceptions of fashion trends. Zara have developed simple but effective communication flows from the stores to the hub of the organisation. Twice-weekly call-offs are made against distribution centre stock using a personal digital assistant (PDA). Other trend-related information is fed back to the design centre. This is what turns the concept of demand-led supply into a reality.

The activities in the design centre, in the manufacturing plants and in the distribution centre are all engineered to achieve fast fashion timescales. This requires attention to many practices and technologies that are addressed in manufacturing and supply chain texts. There is, however, merit in drawing attention to the underpinning ideas that give coherence to the various activities. The key characteristics of the Zara approach to fast fashion can be summarised as follows:

- consumer focus to hear the 'voice of the consumer';
- pull processes;
- speed takes priority over cost;
- flow in small batches;
- right-first-time systems;
- simple communication systems supported by IT;
- 'change' is a given;
- indirect promotion with no advertising budget.

These characteristics are all associated with the just-in-time (JIT) philosophy for manufacturing systems. Originating in the Toyota Car Company, the JIT philosophy has spread globally and has changed the way managers think about their manufacturing operations. JIT has provided a radical contrast to traditional approaches and has delivered massive savings in costs, improvements in quality, reduced lead times, enhanced flexibility and enriched employment for the workforce. However, it has made its greatest impact in producer-led supply chains (Gereffi, 1999) because, to be effective, JIT systems need to be integrated with the sales function. JIT has been implemented only in a piecemeal way in buyer-driven supply chains. It has never been able to achieve its full potential because the retail part of the supply chain has not embraced the JIT approach. However, in the case of Zara, it has. Zara can fairly be described as a just-in-time retailer. It is worthy of note that before Zara became involved in retailing, the company was involved in manufacturing. It would appear that the values and practices of manufacturing have not been lost during Zara's transformation into a global retailer.

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8.8 Future trends

The clothing industry is dominated by retailers who manage their business activities via buyer-driven supply chains. All retailers seek enhanced flexibility and short lead times for their fashion products. This is deemed essential to reduce risk in a volatile market. In order to assess where the industry is going, it is useful to categorise retailers into two broad categories: those who see their company as the customer, and those who see consumers as customers.

Those retailers who see the company as the customer tend not to see themselves as part of the supply chain. They tend to put the onus for flexibility, short lead times and responsiveness on the supply chain. This, as has been argued here, is a strategy with limitations. Additional problems are identified by Birtwistle *et al.* (2003). There is a limit to what can be achieved by this route. This is because these retailers have to build their businesses around forecasting, and product decisions made in this way cannot be easily altered or modified. The trend for these retailers is likely to be a constant struggle to deal with market changes, with compromises being made to deliver only part of the desired responses. Where there is lack of trust in the supply chain, protective strategies are employed to safeguard the future of the businesses involved, and these are likely to have negative impacts on flexibility and responsiveness. The retailers at the head of these supply chains will have limited success at managing risk.

The second group of retailers are those who perceive themselves as an integral part of the supply chain. They recognise that the performance of the supply chain is dependent on the way decisions are made by the buyers and by the relationships that exist between the companies within the supply chain. These retailers will adjust their internal systems to respond to the need for decision-making consistent with the critical path. They will modify their internal procedures so that the procedures are tailored to match desired timescales. Examples of these retailers are provided by Bruce and Daly (2006), with this summary:

> Common to each case was an integrated internal process whereby sourcing, buying, merchandising and design interfaced effectively to enable rapid decisions about the collection to be made. Technology was used in internal processes and the supply chain to convey the design of the collection, to enable changes to be made quickly and to speed up the design agreement and signing off process. In some cases, sourcing and management of suppliers was an integrated aspect of buying, as in the supermarket case. For the specialist fashion company, the technical team liaised closely with the suppliers, together with the buyers, to ensure that the design was interpreted correctly and to speed up the production time. For all three cases, merchandising was a separate activity, but was involved closely in

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> the whole process of ensuring that product was presented in store quickly. (p. 339)

The retailer has a leadership role in clothing supply, and how that role is interpreted and implemented is the crucial factor for future competitiveness.

8.9 Sources of further information and advice

Two useful textbooks on responsiveness in clothing supply chains are Abernathy *et al.* (1999), *A Stitch in Time,* and Lowson *et al*. (1999), *Quick Response.* Two textbooks on the technologies used in clothing manufacture are Cooklin (2006), *Introduction to Clothing Manufacture,* and Tyler (2008), *Carr & Latham's Technology of Clothing Manufacture*.

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9

Developments in apparel knitting technology

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9.1 Introduction

The days of knitwear's association with harsh woollen structures have long past. In the twenty-first century, knitwear has become a contemporary fashion item, with many brands utilising the advanced properties that knitted garments offer to their advantage. Perhaps knitwear owes some of its most recent success to changes in lifestyle. Casual dress has become fashionable, resulting in many designers linking with sportswear brands to promote active ranges which benefit from the structural properties of knitted fabrics. Generally speaking knitwear can be classified in many ways, beginning with construction methods. Section 9.2 of this chapter discusses the various knitting construction methods, introducing the reader to the basic terminology used within the industry. Initially, the principles of knitting are described, outlining common structures used in fashion and clothing applications, and their associated properties. Section 9.3 concentrates specifically on weft knitting technology and details are provided regarding the various production methods and recent technological advance in this area. This leads into a full explanation in Section 9.4 of the shaping technologies commercially available in the weft knitting sector, including the sophisticated three-dimensional (3D) complete knitted garment production method. To close the shaping section the various auxiliary processes involved in the garment's make-up are outlined in Section 9.5, relating specific post-knitting construction methods to shaping techniques. Section 9.6 outlines the notable successes in the history of weft knitting within fashion, beginning with the classic fully fashioned twinset and moving forward acknowledging the works of pioneers such as MacQueen and Pfäuti and their contribution to the development of complete garment production as we see it today. To conclude, Section 9.7 provides an outline of future knitwear trends. This chapter provides essential reading for fashion/clothing students and designers new to the knitting industry.

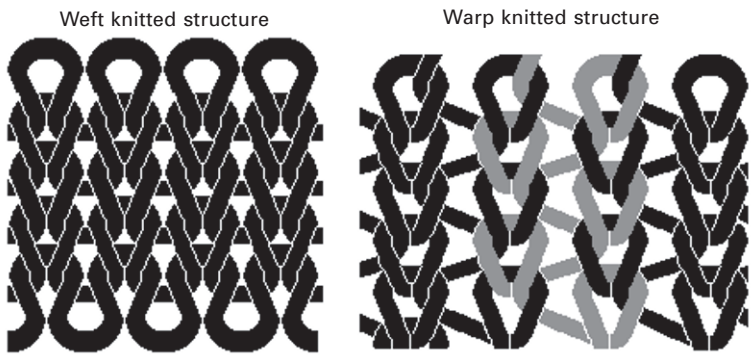
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9.2 Principles of knitting

The term knitting is used to describe a textile structure composed of intermeshing loops of yarn. There are two types of knitted loop constructions currently utilised in fashion (weft and warp). The first method, weft knitting, produces the type of structures commonly associated with hand pin knitting; however, for commercial applications weft knitting is conducted by a knitting machine. The fundamental difference between hand and machine knitting is that every knitted loop produced by a knitting machine has its own individual knitting needle rather than the two pins used in hand knitting (where all the stitches are progressively moved horizontally from one needle to another during the knitting process). Weft knitted structures are easily recognised by the length of yarn forming the knitted loop running continually in a horizontal direction (Fig. 9.1). The types of knitted structure produced are most common in T-shirt fabrics and knitted outerwear. The second method of knitted fabric construction is warp; in contrast to weft knitting many individual ends of yarns are running in a vertical direction throughout the knitted structure. This method of construction generally creates a more stable textile and is largely associated with lace, sports and technical applications (Fig. 9.1).

9.2.1 Knitting terminology

The intermeshing loop shapes that form the knitted structures are referred to technically as 'wales' and 'courses' (stitches and rows). The wales refer to the number of stitches in the knitted swatch, counting them consecutively across the horizontal axis. The courses refer to the number of wales along the vertical axis (beginning counting at the bottom and working upwards to the end last knitted), the greater the amount of courses the longer the knitted swatch becomes. The example in Fig. 9.1 shows four wales and five courses for both warp and weft knitting.



9.1 Knitting construction methods.

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The knitted loop dimensions can be increased or decreased in size by adding or reducing the amount of yarn fed into the loop shape, this is termed altering the stitch length. There is a limit regarding the stitch dimensions, which is strongly related to the yarn diameter, needle size and the knitting machine's needle spacing (the distance in between each needle). In hand knitting, the size of the yarn diameter leads to the selection of the correct needle size, hence, thin yarns are produced using knitting needles of a small diameter. In machine knitting, a similar approach is adopted. The hook of the needle becomes larger and the spacing in between each needle increases for chunky gauge knitwear and reduces for fine gauge fabric. When referring to modern knitting machinery, the needle spacing is represented by a number. This number corresponds to the number of needles per English inch (2.5 cm). Hence, a 2.5 gauge knitting machine has two and a half needles in every inch (2.5 cm) and therefore produces a chunky knitted fabric; alternatively an 18 gauge machine has 18 needles per inch (2.5 cm), thus producing a fine lightweight fabric.

9.2.2 Weft knitting – common structures

There are four base structures recognised within weft knitting (plain, rib, purl and interlock), each providing the knitted fabric with unique properties (Table 9.1 provides a quick reference guide for recognising the structures). The most common base structure within fashion applications is plain or single jersey (as it is often referred to). It is strongly associated with T-shirt materials in fashion applications, and with heavier yarns for the classic knitwear market. The resultant fabric has good drape properties and therefore works well in silhouettes that skim the body. The structure is easy to recognise because it is visually different on the front and back, it has a correct side which should face outwards when worn (the side that is normally visible during wear is often referred to as the 'technical face'), although some designers have made exception and used the reverse side of the structure for fashion applications) Table 9.1 provides further details. Usually when plain structures are used in garments they have welts, cuffs and collars made in a more stable structure to prevent the edges of the plain structure from curling (usually a rib structure or a plain structure folded to create a tube). In contrast, the second base structure, purl (sometimes referred to by manufacturers as 'links–links'), is very stable (no edge curling). This structure is quite decorative and is used frequently in the manufacture of babies' cardigans, like the plain structure it skims the body rather than clinging. The structure naturally collapses in the length once the knitting takedown tension (the applied tension during knitting) has been removed, which results in a heavier fabric than in the plain structure, therefore providing added stretch in the length and significantly improved thermal insulation properties. The third base structures are those

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Table 9.1 Recognising the four base weft knitted structures

	Plain	Purl	Rib	Interlock
Visually	Face of fabric looks different to reverse	Identical faces	Face loops on both sides (may not be equal in number)	Face loops on both sides, Identical faces
Manufactured	Produced on one needlebed	Courses alternate between needlebeds by transfer	Produced on two needlebeds	Produced on two needlebeds
Characteristics	Curls back at selvedges. Curls forward at top and bottom of swatch	Stable – no curling at edges or selvedges	Stable – no curling at edges or selvedges	Stable – no curling at edges or selvedges
Unravels	Unravel from top and bottom	Unravel from top and bottom	Unravel from end last knitted	Unravel from end last knitted
Extensibility	Low extensibility	More extensibility in length than width	Highly extensible	Extensible but not elastic
Weight	Lightweight	Heavier than plain structure	Heavier than purl (good thermal properties)	Very heavy structure (good thermal properties)

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described as ribs, traditionally this structure type is associated with the welts and cuffs of knitted garments. Generally all ribs are extendable structures, which contract to enable the knitted fabric to conform to the body contours. This structure type has become increasingly important in knitted fashion garments – where a tight fitting silhouette is required and the garment must conform to the body's dimensions. The final base structure, interlock, is rarely used in fashion knitwear. It was originally utilised in underwear, however it has been superseded by other structures and now finds uses in technical applications were stability is paramount.

9.2.3 Warp knitting – common structures

Before examining warp knitted structures it should be acknowledged that there are two general types of warp knitting machinery, which are largely associated with different structure types. The Tricot machines are associated with plain structures, while the Raschel machines are linked to open work lace, jacquards and fancy work. Warp knitted structures comprise of yarns that are intertwined in a zigzag formation as illustrated by the shaded wales in the warp structure (Fig. 9.1). It is due to this knitting action that warp structures are more difficult to analyse than weft knitted structures, since they cannot be unroved course by course. This distinct feature provides warp knitted fabrics with the positive attribute of being ladder-resistant.

Unlike weft knitting, where shaping the selvedge is possible, it is only possible to knit continuous widths in warp knitting. The simplest warp knitted structure is the basic tricot (half-tricot) illustrated in Fig. 9.1; however, it is not considered a stable structure and therefore is unsuitable for use in apparel. Once the tension applied during knitting has been released the knitted loops tend to incline. The solution to this problem is to produce a slightly more complex structure termed 'two-bar tricot', which results in a stable fabric. The most popular warp knitted structure is locknit, finding extensive use in the lingerie market.

9.2.4 Warp knitting technology and fashion

Warp knitting can produce a variety of different structure types, providing a whole range of fabric properties; from stretch fabrics used extensively in lingerie and sportswear, to stable structures (and, in the extreme, spacer fabrics) used in technical and medical applications. Fashion applications for warp structures tend to be split into two categories: those intended for functional wear, which require specific fabric properties (lingerie, sportswear, outerwear), or those garments desiring aesthetic properties – e.g. laces, jacquards and nets. In recent years, there have been significant advances in warp lace-producing machines resulting in some innovative fashion fabrics utilising

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lurex and spandex yarns. Despite these advances the fastest growing group using warp knitted structures is by far the technical and medical industries. Applications find their way into diverse structures from car upholstery and mattress covers through to sophisticated medical implants.

9.3 Weft knitting technology

This technology has advanced significantly from its humble beginnings as a home craft. The development in 1589 of the first knitting machine by William Lee appears far removed from the advanced computer-controlled, electronic weft knitting machines that are at the forefront of today's technology. Generally, weft knitting is more diverse and versatile than its sister technique of warp knitting. However, the weft structures produced during knitting have a tendency to be less stable than warp structures because yarn flows freely from one stitch to another. This factor is generally considered positive because it aids the stretch and recovery of garments, allowing the knitted structures to drape well on the human form and assists in the shaping process. It is these attributes that attract designers year after year to utilise weft knitted structures in their collections and ranges.

Weft knitting technology can be classified into four general machine types (circular, fully fashioned, flat-bed and complete garment production), which are discussed in detail in the paragraphs to follow. In terms of fashion and clothing applications, knitted fabric can be produced as open width (a flat fabric that requires cutting to create shaped panels to produce a garment), shaped panels (panels that are shaped during the knitting process) or complete garments (garments that are produced with little or no final make-up): the shaping methods are discussed more fully in Section 9.4. The machine type and related shaping technology determine which type of knitted goods are produced. When shaping technologies are utilised during knitting the speed is reduced significantly because of the complexity of the transfer action, thus resulting in a more costly garment. Historically, shaped knitted panels (fully fashioned) were only knitted when expensive yarns were used, the main benefit was the saving in yarn costs because this manufacturing technique eliminated or significantly reduced the requirement to cut. However, advances in electronically controlled flat-bed machines are increasingly challenging the traditional fully fashioning technology by offering benefits of shaping while simultaneously creating innovative structures.

9.3.1 Circular knitting

As the name implies circular knitting produces a continuous tube of weft knitted fabric. If the desired product is not tubular, the fabric is usually cut down one length and garment pattern pieces are cut from the open fabric

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(much the same as for woven garment production). Most single-jersey T-shirt fabric is produced in this manner. Single jersey is by far the most popular structure manufactured on circular knitting machines (usually intended for the T-shirt and underwear markets), it can be produced using a variety of fibres from high-tech micro fibres for active wear to standard and organic cottons aimed at the high-fashion markets. Depending on the knitting cams and needle arrangement of the circular machine other structures and stitches can be produced – including ribs, double jersey, purl structures, tuck stitches and miss stitches – which can add aesthetic or functional value to the product. The main advantage of circular knitting is the extremely high speeds at which it produces continuous lengths of fabric; thus it is a cost-effective production method for bulk products.

Advances in circular weft knitting technology during the 1990s include seamless garment technology. Underwear and intimate apparel have been the main market area for this technology. However, sportswear is predicted to be an area for significant growth in the future, with athletes striving to become more aerodynamic. Santoni is a major player in the development and production of circular seamless machinery. Currently, their machines are producing weft seamless garments with the added benefits of jacquard patterning capability. More recently, Santoni machines have been involved in the manufacture of clothing and garments with integrated multi-sensory electronics to monitor a variety of body functions, including electrocardiogram and respiration. It is envisaged that seamless garment technology will benefit from the fashion drive for an active lifestyle with a strong focus on well-being. The major concern with circular seamless production is that there are potentially a small number of seams in the gusset and shoulder seams, which may lead to some confusion in the marketplace with the use of the term ‘seamless’.

9.3.2 Fully fashioned knitting (traditional)

This technology is traditionally associated with high-quality knitwear produced using expensive raw materials (cashmere, merino wool and silk). The advantages of this knitting technique are, firstly, the ability to knit shaped panels, thus saving significantly on raw materials in comparison with cutting the shape from a flat knitted panel where a high degree of waste is produced; and secondly a secure knitted selvedge, enabling flatter garment seams to be produced during manufacture. The success of the straight bar frame is accredited to William Cotton for producing a high-speed automatic fully fashioning knitting machine; thus explaining why in industry the technology is commonly referred to as the ‘Cotton’s patent machine’. Historically, this sector of the industry has seen dramatic change and has shown incredible resilience and determination. Its original market was the knitting of socks and the fully

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fashioned half-hose. However, the introduction of circular knitting, and its speed advantage, destroyed this market. The industry quickly diversified into underwear, only again to be challenged by cheaper manufacturing technologies. Finally, the technology of knitting 'to shape' took refuge in the outerwear sector. Nowadays, the machines are still utilised by some traditional high-quality outerwear knitters but are becoming increasingly challenged by the versatility of the modern electronic flat-bed knitting machines.

9.3.3 Flat-bed knitting

In the early days, a variety of flat-bed knitting machines were available, capable of producing a vast array of different textured fabric in flat form only; thus occupying a completely different market sector to either circular knitting (where it could not compete with speed) or fully fashioned knitting (producing high-quality shaped panels). However, through significant technical and software advances the modern world of flat-bed knitting machines (often referred to as V-bed knitting machines) has grabbed the attention of the fashion industry. The modern flat-bed knitting machines are of the type that have two needlebeds arranged in an inverted V-shape and cams that enable sophisticated patterning (knit, miss, tuck and transfer) combined with advanced shaping to occur. This sector of weft knitting now provides the most versatility in terms of colour, pattern and shaping, and is directly responsible for bringing fully shaped knitwear to the forefront of fashion. It is capable of producing highly intricate shaping while simultaneously producing complex patterning sequences through combinations of colour and texture. Recent technological advances over the last 20 years, such as the introduction of variable stroke (the ability to knit short strokes), have reduced the times required to knit a shaped garment significantly. Thus, the once luxury sector of fully fashioned garments has been opened up to the fashion markets, and designers have not wasted any time in utilising this opportunity to introduce fully shaped acrylic, polyester and viscose garments into their seasonal ranges. During the 1990s, knitwear manufacturers learnt to exploit the advantages of computer-controlled, electronic flat-bed knitting to produce commercially viable integrally shaped features in the garments (integral shaping is discussed in Section 9.4.3).

9.3.4 Complete garment knitting

The concept of complete garment production during the knitting process has been traced back to the hand knitting techniques utilising four knitting needles. The famous painting of The Madonna knitting Christ's seamless garment (late 1300) has become widely associated with the idea of complete knitted garment production or 3D seamless garments. However, the concept of machines knitting complete garments was not considered until much later.

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Two pioneers (MacQueen and Pfäuti) in the late 1950s both filed patents relating to methods of producing complete knitted garments. Unfortunately, these ideas were regarded as ambitious and were condemned by the industry. During the mid 1960s Courtauld's research division began a study relating to complete garment manufacture and found that in order to produce garments in this manner more control would be required during the knitting process. This has been a problem associated with seamless flat-bed knitting for many years. The technique of producing a complete knitted garment has been possible using conventional flat-bed knitting technology for some time, but there were problems regarding the complexity of programming, lack of patterning capabilities, takedown and the poor quality of rib structures during the production.

The commercial launch of 3D (complete garment) knitting is accredited to the International Textile Machinery Exhibition (ITMA) in 1995. This saw the first generation of machines capable of producing truly seamless knitted garments. A decade later the technology has moved forward to provide us with 'Wholegarment' technology from Shima Seiki and 'Knit and Wear' from Stoll; these machines are capable of producing high-quality knitwear, where the structures are engineered during knitting to produce a seamless garment. Today, sophisticated clothing can be produced combining both texture and colour with advanced 3D garment-shaping capacities. This technology is aimed at the Western world to enable them to diversify into innovative knitwear markets and lead fashion knitwear forward into a new era. Sportswear and designer knitwear are the obvious choices when predicting areas of product growth for this technology; however, there appears to be great interest in utilising this technology for cost cutting within mass production, which is a disappointing step backwards in terms of fashion and functional innovation.

9.4 Shaping technologies

The versatility of modern weft knitting technology has paved the way for sophisticated garment shaping to occur. Through advances in flat-bed technology, new methods of shaping knitwear have emerged that provide innovative opportunities for designers. Garments produced on flat-bed knitting machines can be classified into four shaping types (cut and sew, fully fashioned, integral knitted and complete 3D garment), which relate directly to the technology type used during manufacture. Cut and sew and fully fashioned production methods are largely concerned with producing 2D panels that require auxiliary sewing procedures in order to produce a 3D garment form (much the same technique as used in woven clothing manufacture); these technologies and manufacturing procedures are well documented by numerous authors including Brackenbury (1992) and Spencer (2001). Integral knitting

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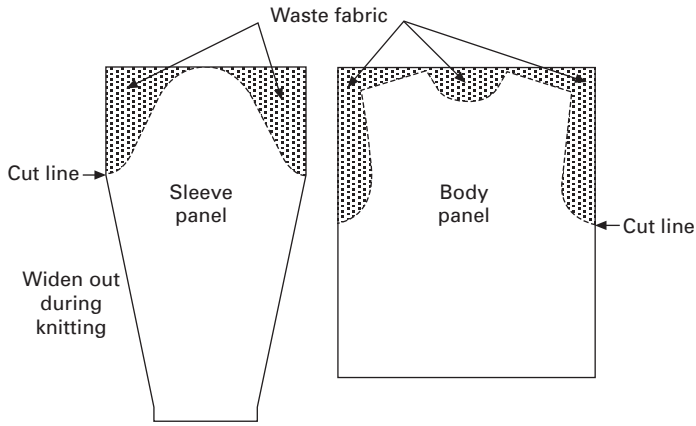
in contrast consists of 2D panels with some evidence of sections taking a 3D form, but not the garment in its entirety. Quite often this is achieved through holding stitches and knitting short strokes (commonly referred to as the 'flechage' technique). The most obvious examples of this technique include knitting collars, lapels, stoles, pockets and buttonholes as part of the panel. Integral knitting removes the requirement for some of the auxiliary sewing processes. The technology type used in the most advanced shaping method (complete 3D garments) has the capability to remove all of the auxiliary sewing processes, thus producing a knitted garment in its entirety. In addition to this level of shaping sophistication, it retains the versatility to produce advanced patterning within the knitted structure and the ability to produce 2D panels (cut and sew, fully fashioned and integral knitting) if desired.

9.4.1 Cut and sew shaping

As the name implies, this manufacturing technique involves the production of continuous lengths of knitted fabric. The fabric is then removed from the machine, laid flat and shaped panels are cut from paper/card templates. Once the panels have been cut to shape they are joined together using an overlocker machine (see Section 9.5). Traditionally, in cut and sew knitwear manufacture, ribs, welts and cuffs have been attached separately as part of the making-up process. Hence, the knitted fabric may have been produced on a circular or flat-bed machine in a continuous length. During the 1970s, skinny ribs were mass-produced for fashion applications using this method of production. Later, the birth of the first fully electronic flat machine enabled jacquard to be combined with many stitch variations, which firmly placed flat-bed cut and sew knitwear at the forefront of the fashion arena. Knitwear dominated fashion in the late 1970s and early 1980s (Brackenbury, 1992) with highly patterned fabrics becoming the vogue.

The second method of cut and sew, referred to by some experts as 'stitch shape cut' (but often termed 'knit to width and widen' by the industry), was again a result of innovation within flat-bed technology. During the late 1980s, commercial flat-bed machines were introduced with a reversible motor (enabling variable stroke knitting to be conducted). This significantly reduced the time taken to knit a small width of fabric and enabled body panels to be knitted to the exact width and sleeve panels to be widened out from cuff to the widest point of the sleeve (sleeve widest); the requirement for the armhole, sleeve head and shoulder shapes to be cut still remained (Fig. 9.2). Historically, cut and sew manufacturing methods have been associated with high-fashion garments often produced with less expensive fibres. The advantages of the cut and sew technique, are quick production times and easy style changes.

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9.2 Knit to width and widen.

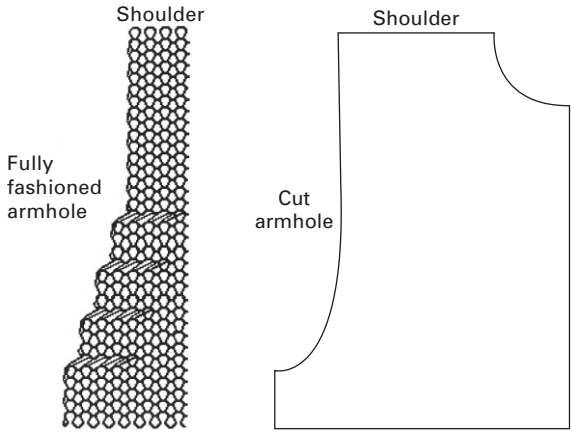
9.4.2 Fully fashioned shaping

Fully fashioned knitted garments are knitted panels where the shaping process has been conducted during knitting. Individual garment panels are shaped through the re-positioning of wales (stitches) during the knitting sequence, hence changing the number of active needles. To form the armhole shape, an action termed 'narrowing' is employed; this is the movement of a single wale or groups of wales towards the centre of the garment (thus reducing the knitting width). In most cases, two needles are reduced in each subsequent movement (Fig. 9.3 illustrates a narrowing of one needle every four courses in the armhole area). If the width of the panel requires increasing, extra needles can become active gradually during the knitting sequence (this is termed 'widening'). Fully fashioned knitwear was historically associated with the luxury market sector, since the technique was used to save yarn during knitting (no, or a very small amount of, cutting in the neck areas was required). However, modern flat-bed knitting technology, through electronics and advanced software has opened up the technique of fully fashioning to a wider sector of the industry. In addition to shaping, the modern flat-bed knitting machine has the added advantage of combining complex colour and pattern sequences. Much of the fashion knitwear on the high street is produced utilising this shaping technology and this is the biggest threat to the classic fully fashioned manufacturing method.

9.4.3 Integral shaping

The original drive for the development of integral knitting technology was to eliminate as many, post-knitting operations (sewing, attaching trims and pockets, etc.) as possible, thus producing savings in post-knitting operations.

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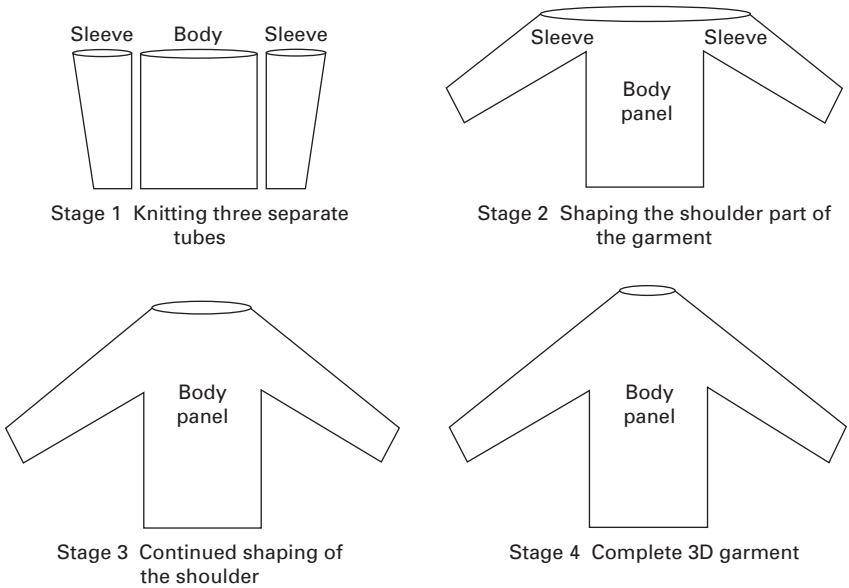
9.3 Fully fashioning an armhole shape.

However, advances in programming software have led to innovative style lines being produced with waist shaping and integral circular welts as buttonstands, not to mention the significant developments in technical textiles. With the improvements in takedown control during knitting, more controlled areas of integral shaping are now possible in garments, resulting in styling innovations for fashion applications that have not previously been possible commercially.

9.4.4 Complete garment shaping

The concept of producing a complete garment that requires minimal or no sewing operations has been around for many years. Section 9.3.4 outlined the notable areas of innovation, landmarks and pioneers; 1995 was a key date for the commercialisation of this technology and since then there has been much development. The basic method of producing complete knitted garments is to knit the two sleeves and body independently on a tubular basis (sleeve–body section–sleeve). Hence, three separate tubes are manufactured; this in itself is easy to understand (Fig. 9.4). The complexity occurs when the three tubes need to be joined together during knitting to form the shoulder part of the garment, Fig. 9.4 illustrates the basic process. Since its launch commercially, complete knitted garment manufacture has significantly improved in terms of patterning and shaping capabilities, through sophisticated programming software and advances in takedown control. Many patents exist relating to various specific techniques involved in the shaping process and methods of production. Two flat-bed machine builders who are leaders in this area are Shima Seiki and Stoll, both having dedicated flat-bed knitting machinery to produce complex 3D garment shaping while still retaining the versatility to knit pattern and texture.

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9.4 Process of complete garment manufacture.

9.5 Post-knitting – construction methods

The construction methods used to join the 2D garment panels produced on a flat-bed machine differ depending on the shaping technology selected during manufacture. If the cut and sew method has been utilised, it is important that the cut edge is secured completely. To ensure the seam is fully secure an overlocker type of machine must be used. It is most common to use the three-thread type to ensure that the seam is secure and the raw (cut) edge is bound securely. The advantage of a three-thread overlocker is the extensibility it provides in the seam. Often the seaming thread is core-spun polyester while the cover threads binding the raw selvedge edge are polyester bulked threads to provide maximum cover and flexibility.

9.5.1 Alternative post-knitting construction methods

The traditional construction method associated with fully fashioned shaped panels involves a manufacturing technique termed ‘linking’. This is an expensive and time-consuming process, that is heavily reliant on a highly skilled operator. It involves sliding individual knitted loops onto metal points from each of the two panels that are to be joined. Each linking point holds two loops – one from the front panel and the second from the back panel – once all the loops have been placed on the individual points a chain stitch secures them. The advantage of this method of construction is that when a

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course of wales are joined (producing a horizontal join) there is no visible seam inside the garment, the linking join lies perfectly flat to the body. Alternatively, if the selvedges of the shaped panel are joined using the linking technique (producing a vertical seam, often referred to as 'waleing' in the industry) a visible seam is the result. This seam type is relatively flat compared with an overlocked seam.

A less expensive method of joining fully fashioned selvedges is a technique called 'cup seaming'. This operation is much faster than linking and does not require the same level of operator skill. The machine derives its name from two large metal cups, which the selvedge of the garment is fed into. A continuous chain stitch and a small seam are formed (two to four wales depending on the gauge), the resultant seam is not of the same precision as a linked seam and may appear unstraight on some knitted structures. Cup seaming is not suitable for insecure knitted edges (most shoulder seams), so quite often the resultant garment is a combination of shoulder areas that have been linked and cup-seamed selvedges.

9.5.2 Cost-cutting construction methods

Outlined in the above paragraphs are examples of low-, medium- and high-quality construction methods. This list is not exclusive and other methods do exist. Brackenbury (1992) provides significant detail regarding various knitted garment construction methods, complete with fully illustrated diagrams for a more comprehensive read. Historically, it was relatively simple to relate the shaping method used with the appropriate garment construction technology. However, with the fashion industry exploiting the versatility of flat-bed knitting machines these boundaries have blurred significantly. What looks like a high-quality, fully fashioned shaped garment at first glance may not be constructed using the traditional high-quality construction techniques. One popular combination in high street fashion knitwear is to shape the armholes during knitting but to cut the shoulder shape post-knitting and overlock the seam. Hence, the armholes bear resemblance to a high-quality traditional fully fashioned knitted garment (costly and highly skilled post-knitting manufacture), while the shoulder seams use a lower quality construction method (less expensive and less skilled). Perhaps the shoulder seam is considered less important in fashion applications because of its position and the armhole is considered essential because it is a visible aesthetic style line.

9.6 Weft knitwear in fashion applications

Knitwear has been utilised in fashion for many years, perhaps the first example of designer knitwear should be credited to the Elizabethans and their desire

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for the highly embellished finest knitted silk stockings. Historically, knitwear has diversified from hosiery to underwear and, finally, outerwear. During the 1920s, knitwear took two different directions, fashion knitwear found new uses for cut and sew jersey in outerwear applications (such as dresses), and the great leisurewear boom (Brackenbury, 1992) provided a market for the more expensive classic fully fashioned shaped knitwear to thrive. By the 1930s, classic British knitwear was recognised as the world leader, Pringles had appointed its first knitwear designer in response to the growth in continental knitwear fashions (Gulvin, 1984). Designer knitwear in its true sense was born; the ladies' twinset grew in popularity both in Britain and abroad. After the war years (late 1940s), fashion generally saw a dramatic change in styling. The glitz of Hollywood was the stage for fashion; the general population looked to the stars for inspiration. Classic knitwear styles became the vogue of women's style, with many celebrities adopting the classic fully fashioned British twinset (Gulvin, 1984).

9.6.1 The growth of flat-bed knitting in fashion

Flat-bed knitting machines historically were used to produce trims. This was because they could not compete with the traditional fully fashioned machines' shaping capability, or the speed achieved by circular weft knitting. However, the first motor-driven jacquard flat-bed machine in 1926 changed the role and contribution of this machine to fashion. It provided knitwear designers with patterning capabilities that had not previously been possible and thus established for itself a unique place within fashion. Over the next few decades, the flat-bed machine was transformed from a mechanical mechanism to a highly sophisticated computer-controlled machine that was capable of advanced shaping and patterning simultaneously. The next paragraph highlights the key developments in flat-bed knitting from the pioneering work in the late 1950s of MacQueen and Pfäuti, and the effect these developments had on fashion.

The value of MacQueen and Pfäuti's works relating to complete garment production, like so much innovation, was not really appreciated until much later in history when the knitwear industry began to evolve naturally into 3D knitted garment production. However, their work prompted investigations into complete garment production by the Courtauld's team (although never commercialised), which led to the development of the presser foot in the late 1960s. The introduction of the presser foot to commercial machinery at ITMA in 1975 brought about a new era for patterning capabilities in flat-bed knitwear. A second notable development in the early 1970s was the first flat-bed machine with electro/mechanical selection, this enabled jacquard patterning to be conducted easily (Hunter, 2004). Finally, in 1975, the first fully electronic flat-bed machine was introduced by Stoll (Spencer, 2001). All these

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developments influenced fashion knitwear resulting in a boom in the 1970s and 1980s, especially in the ladies' fashion markets (see Section 9.4.1). This was helped by the fact that design education was catching up with the new technology (Brackenbury, 1992). The designer's of the time optimised bold patterning, assisted by the advances in computer-controlled knitting during the 1980s. However, the most notable effect that flat-bed knitting has had on fashion is in the area of shaping. In 1987, a knitting machine was developed that was equipped with variable stroke, this caused a shift in fashion – especially during the 1990s. Shaping now became cost-effective in lower quality yarns and could be combined easily with colour and texture. Traditional British knitwear brands linked with prominent designers and, for the first time, flat-bed knitting technology and its products began challenging traditional classic manufacturing techniques. The 1990s were about exploring the new technological developments and their implications in terms of fit and style – the machine capabilities were explored to assess the limits of the technology.

By the mid 1990s, knitwear style lines had become more tailored, especially in rib structures, and integral knitting opportunities were beginning to be exploited within shaped knitwear. In 1995, knitwear technology matured with the introduction of the first generation of complete garment machines. It has taken time but, slowly, complete garment production has evolved, becoming increasingly commercialised, with some retailers choosing to acknowledge this method of production on the swing tags while others are simply retailing the knitwear (perhaps without the consumer ever realising that the garment has no seams). Knitwear has become a key item of clothing in the fashion market, fashion authors such as Sue Jenkyn Jones (2005) acknowledge knitwear's significance in fashion, especially in the new sports and active wear collections. Today, the flat-bed machine's versatility cannot be superseded by the other knitting technologies. Flat-bed knitting technology is the driving force behind knitwear's innovation in fashion. Exploring and exploiting the opportunities require great technical expertise and competence, and often result in the designer and technician working as one.

9.7 Trends in weft knitting

Knitwear has gained enormous popularity in fashion applications due to its unique comfort properties, which are derived from its structural configuration. Recent lifestyle trends have resulted in casual dress becoming more readily accepted in fashion generally and, as a result, fashion outlets have been awash with knitted styles. Foreign imports from countries with cheap labour are breaking into new markets by devising new garment construction methods to simulate quality knitwear techniques and, as a result, more shaped knitwear is available in value retail outlets. This has forced many luxury retailers to

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look towards new technological advances in knitting machinery to provide inspiration in terms of quality and design capabilities.

Fully fashioned shaped weft knitwear has and will remain popular for the foreseeable future in both the high street and the designer collections. New technologies and programming software in the weft knitting sector have opened a window of opportunity for innovation in terms of combining patterning, texture and shaping with superior garment fit. There is still further development to be explored regarding the newest weft knitting technologies in the marketplace. However, it can be predicted that this will be exploited primarily in the luxury sector, elevating it to even greater heights for innovative knitwear styling.

9.7.1 Exploiting complete garment knitting

Since the commercial birth of complete garment knitting in 1995, the needs and dynamics of the apparel industry have somewhat changed. Initially the industry was slow to adapt to the idea of complete garment production, probably due to style shaping constraints. However, the new generation of complete garment weft knitting machines have become easier to use and more reliable. The market's acceptance of the technology has fuelled an expansion in the development of product and manufacturing knowledge which has resulted in complete garment technology becoming more widespread in fashion applications. Since the birth of the new millennium, there has been a steady stream of styles appearing in the commercial marketplace in both designer and high street collections. There are ample marketing opportunities to create customer awareness within the brands; some of the larger retailers are already beginning to exploit this by introducing swing tags on their merchandise, thus introducing customers to the value-added benefits that this technology offers. Complete garment knitting technology has evolved to be dynamic and is now accepted in the global community. Words such as 'Wholegarment' and 'Knit and Wear' link us to specific complete knitting technologies developed by global leaders and it can be predicted that there is likely to be further significant growth in the clothing and fashion markets. Currently, the world's industries are still in the experimental stages regarding complete garment production and there are many avenues to be explored and developed, providing interesting innovation opportunities.

9.7.2 Complete garment technology providing competitive advantage

The technology in general appears to be advancing along three paths. Firstly, companies utilising the technology to save production costs, can produce some garments in their entirety in as little as 30 min. This is increasingly

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important with the growth in fast fashion in the global fashion industry. The requirement for shorter lead times as a result of labour-reduced production is becoming more popular, perhaps providing companies with the luxury of keeping a proportion of their production near to their consumer markets rather than relying entirely on low-cost countries. Secondly, the technology is used by companies that are developing new styles and utilising the benefits of fit, in the luxury ends of the markets. Lightweight complete garment knitwear is now possible, making knitted styles available that are both fashionable and functional with beautiful silhouettes conforming to the bodies' dimensions. Finally, the largest area of predicted growth lies in the active sportswear markets, where performance and functionality is paramount. Perhaps the biggest opportunity for complete weft knitted garments will be to challenge the circular machine's stronghold in sports apparel, producing garments that are both functional and fashionable.

9.8 Sources of further information and advice

Many of the general textile publications cover some aspects of knitting technology. However, for more specific information, David Spencer's (2001) *Knitting Technology* (currently in its third edition) provides in-depth information regarding the fundamental principles of both weft and warp knitting, and the complex aspects of knitting science. Various different knitting machines and related technologies are discussed in detail. The breath of this publication appeals to both scholars and professionals alike covering a wide range of applications in knitwear from clothing/fashion through to advanced technical applications. Further information relating to knitwear and knitted garment technology can be found in Brackenbury's (1992) publication. This provides a comprehensive read on issues relating to weft knitted shaping technologies (with the exception of complete garment) and post-knitting construction methods. The reader will value the many illustrations to assist with the understanding of what otherwise may be considered complex processes.

In terms of innovation in knitwear design, *Fashion Design* (Jenkyn Jones, 2005) predominantly focuses on the fashion industry and is intended for fashion scholars. However, it is interesting that this publication separates knitwear opportunities from mainstream womenswear thus demonstrating that specific skills are required for designers intending to pursue their career in this sector of the fashion industry. Throughout the book, there are snippets of valuable information related specifically to knitwear, illustrating knitwear's growing significance in high-fashion markets. A further publication entitled *Knitwear in Fashion* (Black, 2002) also supports knitwear's place as an item of contemporary fashion. Black's publication encompasses knitwear as an art form, including sculpture, and many examples of contemporary designer knitwear are provided. Throughout the book there are beautiful illustrations

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and specific reference is given to new technologies that have had an impact on fashion knitwear.

Despite the usefulness of specific publications relating to the knitting and knitwear industry, technology is advancing at such a pace that journal publications offer the most up-to-date comprehensive read. Information regarding trend innovation, technological advances and marketing briefings are readily published to keep the industry abreast of the new developments. *Knitting International* provides an archive of information related to the knitting technology evolution, including reviews from machinery (ITMA) and trend exhibitions. In terms of marketing information *Drapers* provides a valuable source of knowledge and up-to-date information regarding current and predicted market trends in both fashion and knitwear markets.

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10

Technological advances in sewing garments

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10.1 Introduction

For the past century, the clothing industry has been dominated by one simple and long-lived tool, the basic sewing machine. Its importance can be described as not only facilitating entry into the industry, but also virtually dictating its structure. The past three decades have seen the revolution of the microprocessor (the silicon chip) on which much of our existing technology depends. This small component has been largely responsible for developing the sewing machine into one of the most versatile and intricate pieces of engineering used in industry today. As the sewing machine has continued to prosper, other types of equipment have evolved along with it. Most clothing companies today will have within their walls a combination of progressive equipment of the latest specification and design. Methods of production have advanced to meet the ever-increasing needs of the consumer. Factories have to be lean, mean and, above all, disciplined environments in order to survive in an increasingly competitive world. Companies have to be able to change and adapt to the market place more quickly, and more efficiently, and have faster response times if they are to survive.

In order to have a successful clothing industry, you also need the resources necessary for the industry to survive. This involves not only the technology that the business needs but also the most important resource of all, the work force. Without a well-disciplined and well-trained work force you deprive the business of the skills and expertise needed to make the business successful.

Throughout this chapter, we will concern ourselves with the knowledge surrounding some of the technologies that are essential for a modern clothing manufacturing company. It is a chapter for students who may become future managers in industry. Clothing machine engineers, supervisors or current managers may also find it of interest.

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10.2 The history of sewing

The use of clothing dates back to the beginning of the history of mankind, the purpose being principally for protection and, with the development of civilisation, adornment. Early methods of construction utilised methods of lashing/joining pieces of skin together, which can be compared with stitching used today. Primitive sewing tools such as awls and needles – made from bone, fishbone, spines from plants, wood and bronze – give evidence of the sewing techniques of prehistoric times. It was not until the middle ages that sewing needles were made from steel and the first efforts to sew with a machine came in 1750 by an Englishman named Weisenthal.

In 1790, an English joiner named Thomas Saint applied for a patent for a wooden sewing machine, which produced a chainstitch. This was a very primitive machine with very few moving parts but it was the beginning of a revolution in clothing manufacture. In 1830, a French inventor, Barthelmy Thimmonnier, built about 80 wooden sewing machines, all of them apparently capable of producing quite different stitches but his success was brief. Tailors, worried about this threat to their livelihood, completely demolished his shop and tools. Thimmonnier himself narrowly escaped a lynch mob. In 1890, a German hosier, Balthasar Krems, devised a machine able to sew the edges of caps with chainstitch. Some of the features were amazingly progressive and are still found on specialised machines to this day.

As the decades continued, more and more machines were invented and developed. Wooden machines were replaced with metal ones producing an array of different stitch types for special applications. By 1850, the sewing machine was beginning to catch on and there were about 104 000 machines in the USA alone. Everywhere, enterprising mechanics were beginning to design different types of machines and despite the advances of technology over recent years, there are fundamental similarities in the machinery that remain to this day.

Over the past 90 years, the main emphasis for sewing machine development focused on stitching speed and reliability, and, more recently, on efficiency, flexibility and automation.

The single-needle lockstitch machine, known in industry as the flat machine, is the most commonly used machine in the industry and most companies have this type of machine on their premises. The basic operation of the sewing machine has not changed but the electronic sub-systems allow for flexible operation (Fig. 10.1).

10.3 Examples of sewn products

An example of the diversity of the sewing machine is indicated in the great variety of sewn products available. To name but a few, these include: clothing – fashion, performance, protective; automotive – seat covers, seatbelts, airbags,

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10.1 Example of a modern sewing machine commonly used in industry.

tyres; domestic – upholstery, bed linen, table linen, curtains; shoes; hats; gloves; luggage; ventriloquist dummies; cuddly toys; yacht sails; parachutes; hot air balloons; bouncy castles; tents; climbing harnesses; sacks; conveyor belts; bookbinding.

In considering these examples, it can be appreciated that a seam introduced to the product must perform under a range of circumstances to varying degrees of durability and reliability.

10.4 Development of the industrial sewing machine

It is possible to categorise industrial sewing machine units into four types and each will be considered in turn in the sections below.

- basic sewing machines.
- mechanised (short and long cycle) machines.
- semi-automatic machines.
- automatic transfer lines.

10.4.1 Basic sewing machine unit

In general, a sewing machine consists of:

- a sewing head;
- a machine bed;

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- a work-top;
- a machine stand;
- a drive motor;
- a treadle.

Sewing head

This forms the main mechanical element of the Integral Sewing Unit (ISU). The horizontal component of the casting (horizontal arm) houses the top shaft (excluding over edge machines); this is often the main drive shaft. The top shaft is usually driven by a V-belt connected to the drive motor pulley wheel and the balance or hand wheel of the top shaft. However, this is not always the case and some direct current (dc) motors mount directly to the top shaft (see section on Drive motor p. 203). The top shaft is supported at both ends of the horizontal arm on bearings, which are lubricated by gravity or a splash feed oil system on standard machines and by a pressure-fed system on high-speed seamers.

The top shaft imparts movement upon all other driven mechanisms within the sewing head by way of a toothed (timing) belt or rigid drive shaft and gears to the bottom shaft which drives all the mechanisms below the bed including feed and stitch forming elements. The top shaft generates the needle bar movement and the action of the needle thread take-up mechanism. The rotary motion of the top shaft is transformed into a reciprocating vertical movement by means of loose pin connections to a balanced cam on the end of the top shaft; this constitutes the needle bar drive assembly.

Let us look more closely at the components that make up the sewing head of a standard lockstitch machine. As with the standard machine, the needle thread take-up is driven by an eccentric cam and pivot coupling on the top shaft. It is the bottom shaft that drives the fabric feed mechanism via ancillary shafts often referred to as rocker bars. These impart the forward and backward motion onto the feeddog along with the rise and fall of the device. It is the bottom shaft that drives the stitch-forming mechanisms, which operate below and/or around the fabric plies. A sewing machine head will usually only offer one stitch type. However, a stitch type exists – a combination stitch – that is made up of a chainstitch and an overedge stitch, which can be used together or as separate stitch types by the omission of one or more threads.

Machine bed

The shape of the machine bed is principally governed by the nature of the sewing operation. The volume of fabric that passes beneath and around the needle and the amount of movement required on this fabric, determines this.

Flat bed. The primary use of the flat-bed machine (Fig. 10.2) is in garment

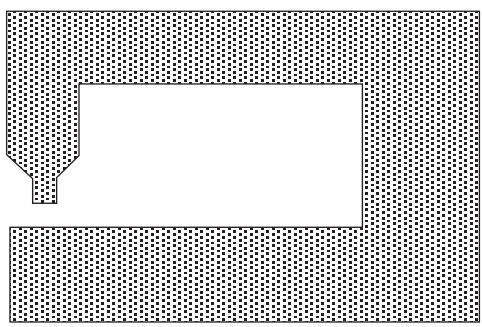
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manufacturing where large open parts are to be joined, when more than just the seam allowance must pass to the right of the needle. The seaming of flat or surface parts can be made easier because it is possible to mount guides and markers upon the bed.

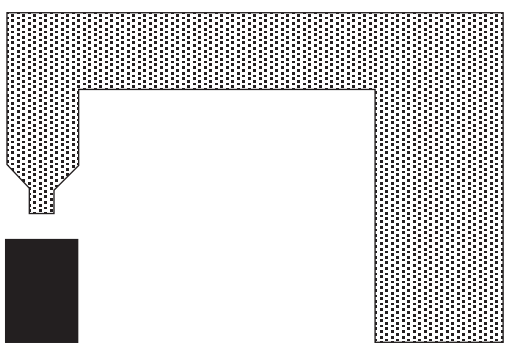
Cylinder and post bed. This configuration is used when parts are small or curved and when the operation is being performed on partially closed components (i.e. hemming a trouser leg). The post bed is particularly common in the footwear industry (Fig. 10.3).

Feed off the arm bed. This bed configuration is used when the product part is being closed into a tube and the final seam is introduced by the feed off the arm machine (i.e. outside leg seam of a pair of jeans) (Fig. 10.4).

Overedge Bed. By its very nature, the overedge machine requires very little clearance to the right of the needle because excess fabric is trimmed by reciprocating blades as stitching takes place. The bed may be raised from the work-top in order to allow long fabric pieces to fall away to the rear more easily (Fig. 10.5).

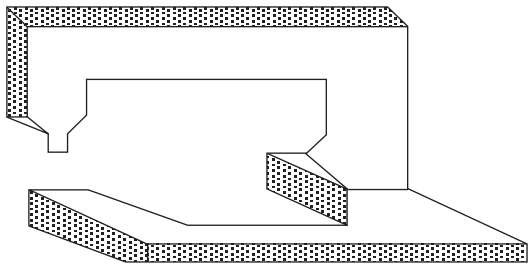


10.2 Representation of a flat-bed machine.

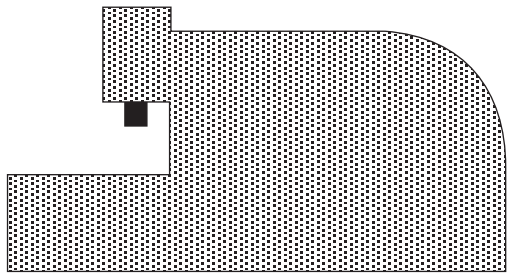


10.3 Representation of a post-bed machine.

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10.4 Representation of a feed off the arm bed machine.



10.5 Representation of an overedge/overlocking-bed machine.

Work-top

Once again, as dictated by the product and nature of the operation, large fabric pieces must be supported by the work-top surface or suspended by an elevated arm (extremely large work surfaces can be seen in curtain or bed linen manufacturing units). It is important not to allow the size of the work-top to inhibit factory layout. Some work surfaces may be split-level in order to reduce overall dimensions but maintain surface area. The science of *ergonomics* is often brought into play by workspace designers.

Machine stand

The frame upon which all of the sewing machine system elements are mounted – the stand – is designed to allow optimum space at the front, to allow access to the sewing head, while supporting the drive unit in a stable position at the rear. In fact, there is some evidence (from America) that sitting too close to the sewing machine motor can lead to cancer in the lower abdomen. Stands for use in team-working environments (where operators move freely from machine to machine and work in a standing position) are quickly adjustable in height to accommodate variations in operator stature.

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Drive motor

Several different types of motor exist today:

- manual friction clutch;
- electromagnetic clutch motor;
- dc motor;
- alternating current (ac) motor.

The first two can be described as continually turning motors; these are most commonly powered by three-phase electricity and have an output in the order of half a horsepower. The manual friction clutch motor operates as follows. The sewing machine is connected to the pulley wheel of the clutch assembly via a V-belt. When the treadle is depressed the clutch plate is pulled onto the continually revolving flywheel of the motor. The maximum speed of such a motor is around 4000 rpm and, by altering the ratio of drive pulley sizes, the machine can be made to run at speeds greater or lower than this.

The electromagnetic clutch motor operates in a similar way to the manual friction clutch motor in that a clutch plate is drawn onto a continually running flywheel. However, in this instance, the clutch plate is drawn onto the flywheel by an electromagnet. The forward movement of the treadle governs the strength of the electromagnetic force attracting the clutch plate assembly. It was the use of this type of motor that allowed the development of electronic positioning motors. A positioning motor allows greater control over the action of the sewing machine. It means that each time the machine stops – or is required to do a certain task – the position of the top shaft (and hence all other mechanical elements) can be guaranteed. As an example, the needle positioning system operates as follows: The treadle is connected to a code switch, which generates a grey code binary output (a binary sequence where only one bit changes each time) (Table 10.1) on the motor control panel. Each logic combination relates to a step in the sewing machine speed or an actuating position of the treadle. When the treadle is brought back through the resting position (as shown on the grey code in Table 10.1) the machine is running at 200 spm, the positioning speed. An optical shaft encoder (called a synchroniser) mounted on the top shaft feeds a signal into the control panel each time the needle is in the needle-up position (take-up at top of stroke) or needle-down position (needle risen by 3–4 mm) indicating that the machine can now be stopped in either of these positions. This allows automatic trimming of threads or presser foot lift along with needle up positioning to allow entry of the work piece.

In a more direct manner dc motors offer similar functions. There is no clutch assembly on a dc motor, which only runs when the sewing head is in action. They are not running continuously thus reducing the power consumption and noise output considerably. In recent developments, the more compact

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Table 10.1 Grey scale used by EFKA control panel

Step	Logic code
FL + T	1100
FL	1000
0	0000
1/2	0100
1	0110
2	1110
3	1010
4	0010
5	0011
6	1011
7	1111
8	0111
9	0101
10	1101
11	1001
12	0001

FL : Foot lift
T : Trim

dc motor has been moved from sub-bench mountings to a position directly on the balance wheel and is now integral to the horizontal arm itself.

Treadle

The treadle is the principal connection between the operator and the sewing machine drive motor. Its operation is used to generate many of the sewing machine functions, starting with the actual sewing and – on electronically controlled machines – including foot lift and thread trimmings. As already mentioned, the treadle either directly pulls the clutch plate onto the flywheel or operates a code switch; another method employs a Hall effect device to detect treadle motion and generate a proportional signal to the electromagnetic clutch. In some cases, additional actuators can be introduced into the line of the treadle such as air or vacuum switches, which will engage cleaning or cooling devices when the treadle is actuated or released.

10.4.2 Mechanised (short and long cycle) machines

These are machines that still require the operator to place and control parts within the sewing area but which sew a predetermined stitch line or pattern. Such machines include:

- bar tack machines;
- buttonhole machines;
- button sewing machines;

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- pocket welt machines;
- spot tack machines.

In general, they are powered by continually running motors that, when engaged, power the sewing head for the duration of the stitching cycle. The motion of the feed system is generated from stitch cams, which can be engineered to give different seam profiles.

10.4.3 Semi-automated machines

These offer many features similar to mechanised machines but are electronically controlled and are hence more flexible. Parts are still entered by a human operator but are subsequently clamped and moved by an *x*–*y* stepper motor arrangement, which can be reprogrammed to give different seam profiles.

Some of the examples already given (buttonhole and button sewing machines) now use this technology. A principal application has been programmable bar tack machines, which can produce basic patterns (i.e. on seat belt mountings). Other applications include:

- semi-automated serges;
- semi-automated leg seaming machines.

10.4.4 Automated transfer lines

The later part of the 1980s and the early 1990s saw investment by both the USA and Japan in fully automated sewing systems. In the USA, the Textile and Clothing Technology Centre ([TC^2]) developed a transfer line system for producing men's trousers, while, in Japan, the Ministry for Trade and Industry (MITI) sponsored research into a robotics system for the manufacture of ladies' jackets.

The reality is that it is extremely difficult to use robots to handle limp materials such as apparel fabrics; this will be discussed later in this chapter. However, some offshoots of the research into fault detection and control systems have transferred over to industrial applications quite well, i.e. thread break detection and fabric fault detection.

10.5 Advances in sewing-needle design

Factors to consider when choosing a needle are:

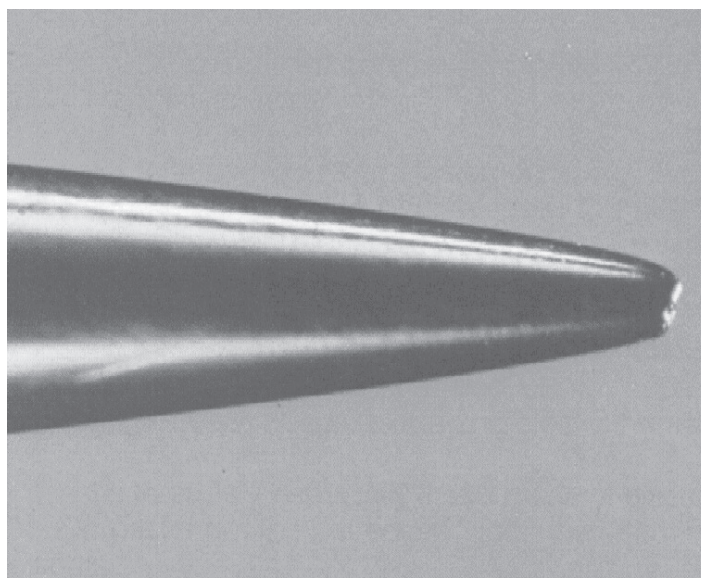
- fabric type;
- fabric density;
- fabric composition;
- type of machine;

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- type of sewing thread;
- fabric thickness.

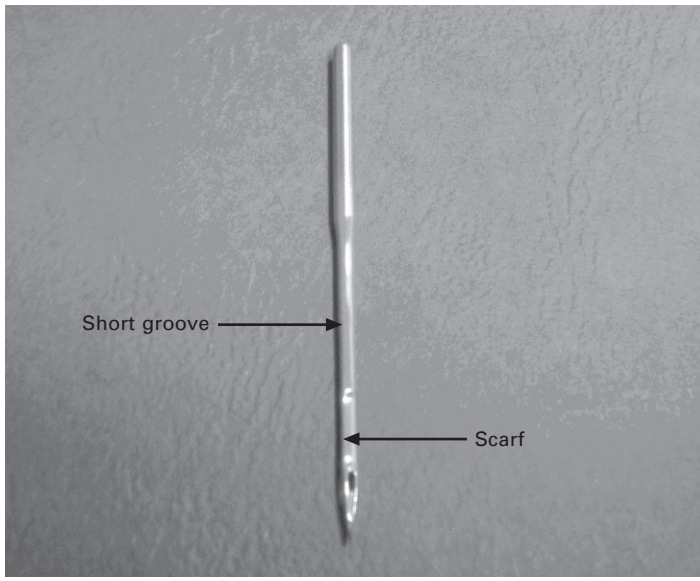
The most important aspect of needle design is the needle point because it has to penetrate the fabric without causing any damage to the material. It is also the most diverse part of the needle due to the many different types of points used. These needle points are designed for sewing on many different fabric types and seams. When fabrics are stitched together, the impact from the needle as it penetrates the fabric can cause buckling and distortion of the yarns and the fibres and even breakage. The strain on the yarns increases if the needle is damaged (Fig.10.6), thereby causing the fibres to rupture and reducing the seam strength significantly. The following factors need to be taken into account in order to help avoid this problem:

- use a needle with the smallest diameter possible for the fabric and seam being sewn;
- adapt the opening of the needle hole on the sewing plate to fit the needle size;
- use a sewing thread with the correct diameter for the needle eye;
- use the correct needle point for the type of fabric you are sewing;
- consider whether the type of seam that you are using to construct the garment could be changed or use multiple seaming in order to divide the strain;



10.6 Example of a damaged needle point.

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10.7 Needle component parts.

10.5.1 Component parts of the needle

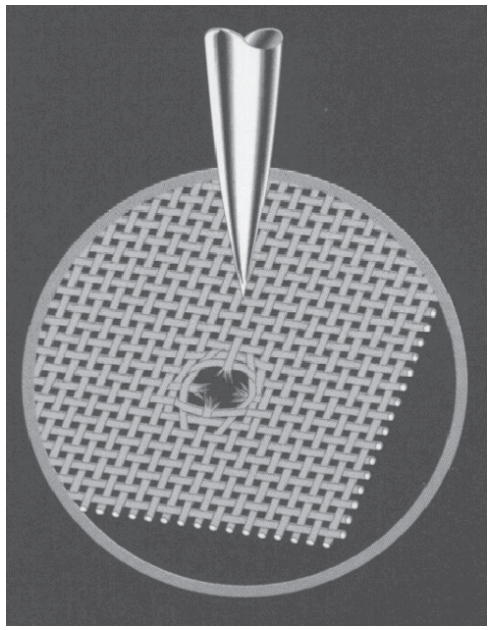
The component parts of the needle are:

- butt;
- shank – the section that fits into the needle bar of the machine;
- shoulder;
- blade;
- long groove – the grooves that are channelled into the blade are designed as a protective channel for the sewing thread;
- short groove – some needle types have a short groove that runs from the scarf of the needle up to the shoulder (Fig. 10.7);
- needle eye – this is threaded with the sewing thread;
- scarf – the flattened part of the needle, so designed to enable the sewing mechanism (in the case of a lockstitch, the sewing hook) to pick up a loop of the sewing thread and thus form a stitch (Fig. 10.7);
- needle point – first point of contact with the fabric;
- needle tip.

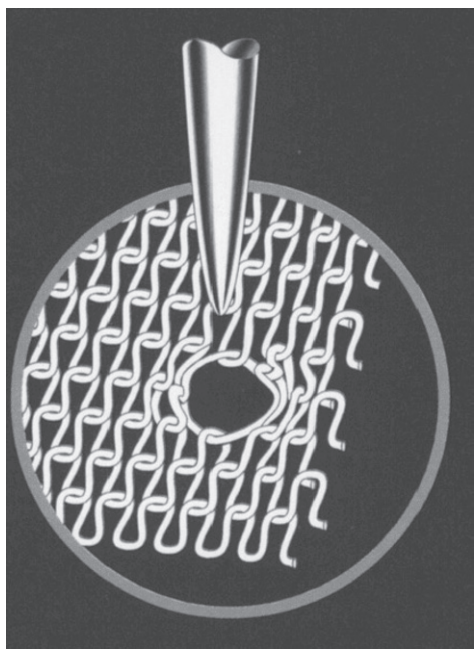
10.5.2 Needle points

There are two main types of needle points; sharp points (Fig. 10.8) and ball points (Fig. 10.9). The type of needle chosen is very much dependent on the type of fabric being sewn. For example, sharp-point needles cannot be used

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10.8 Sharp-point needle.



10.9 Ball-point needle.

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for knitwear because the sharp point will damage the fibres of the material; ball-point needles are used for knitwear because they push the knitted loops apart without damaging the fibres in the material. It is important to note that for both types of needle point, needles should be changed regularly. Sharp-point needles (Fig. 10.8) can be used for:

- very densely woven materials, e.g. micro fabrics and silk;
- coated materials;
- heavy woven materials, e.g. tent awnings;
- thin smooth materials;
- normal seams in shirt stitching (shirt collars, cuffs).

10.6 Advances in sewing-thread technology

Overview

Sewing thread is an integral part of many items that we use daily. The various components of our apparel are joined with thread but what about the string that is attached to our tea bags? What would happen to the upholstery, seat belts and head liner of an automobile if the thread were removed? What about the seams in tents, backpacks, sleeping bags and other camping equipment? How are the components of baseballs and footballs joined? Each of these products requires a thread with different physical properties to achieve optimum performance. When the many uses of thread are considered, the complexity of designing a thread becomes apparent.

Factors to consider when choosing the right thread are:

- sewability of the seam;
- thread loop strength;
- linear strength;
- elongation;
- shrinkage;
- abrasion resistance;
- colour fastness;
- resistance to chemicals, heat, light, etc.

In addition, when sewing the garment together in production, other factors to consider are:

- the required seam strength;
- type of seam;
- stitch type;
- stitch density (stitches per centimetre);
- type of material being sewn;
- type of sewing machine and related equipment;

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- conditions under which the product must perform;
- normal life of product;
- cost effectiveness.

It becomes obvious that there is a lot more to sewing thread than meets the eye and the science that goes into producing good threads is complex and extensive.

10.6.1 Fibre science – Where do the fibres come from?

The fibres that go into modern sewing threads come from three main sources: plant fibres; protein fibres; and manmade fibres. Examples of plant/natural fibres are: cotton; flax; jute; ramie; and hemp. Examples of protein fibres are: wool; goat; silk; and cashmere. Manmade fibres are made from various chemicals, or are regenerated from plant fibres. Examples of manmade fibres are: polyester; polyamide – (nylon); acrylics; viscose, made from wood bark; Kevlar, a high-performance fibre; and Nomex, a high-performance fibre.

10.6.2 The importance of a good thread

During sewing, most action takes place out of sight underneath the material being sewn, when the needle eye disappears through the material the needle thread is subjected to a high degree of stress and strain: every piece of thread passes through the needle eye more than 30 times before being stitched; needle temperatures of over 260 °C are common; thread speeds of up to 150 km/h can be reached.

The selection of the wrong thread type or use of inferior quality threads lead to increased machine stoppages and a higher percentage of substandard goods.

10.6.3 Threads and stitches

As has been noted, the choice of thread is influenced by the kind of stitch. Two of the most important are the lockstitch (ISO 4915 stitch number 301) and the chainstitch (ISO 4915 stitch number 401). Characteristics of the lockstitch include the following:

- Often referred to as ‘double lockstitch’, this stitch type is formed by interlacing a needle thread supply with the bobbin thread supply underneath.
- These stitches are very secure as a break in one stitch will not cause the seam to completely unravel, although it will compromise the overall seam performance.
- Stitches are formed with a single needle thread and a bobbin thread.
- This is the most widely used stitch in low volume production.

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- The stitches exhibits great strength and resilience if correct thread types are used.
- Stitches can provide adequate extension (up to 30%) for comfort stretch garments.
- Stitches have the same appearance on both sides and it is possible to match threads to different fabric ply colours.
- This is the only stitch to reliably sew around 90° when pivoting the fabric at the needle point; it is therefore very important for top-stitching (collars and cuffs, etc.).

Characteristics of the chainstitch indicate the following:

- This stitch is formed by the interlooping of a needle thread with a separate looper thread on the underside of the fabric.
- Chainstitch is often referred to as a 'double-locked stitch' because each needle thread loop is interconnected with two loops of the same single underthread.
- Chainstitch has the appearance of lockstitch (301) on the surface with a double chain underneath;
- Chainstitch exhibits good strength and increased extension/recovery properties due to lower static thread tension and interlooped threads.
- It is less prone to pucker, again due to lower static thread tension and interlooped threads on the underside.
- Chainstitch is excellent for long seams because of continuous thread supplies.

10.6.4 Thread characteristics

1. Tensile strength. This is the force applied to breaking point. The value is commonly expressed in kilograms.
2. Elongation. This is the amount by which the thread is extended before breaking and is expressed as a percentage of its original length. The consistency of this characteristic is crucial for the thread's sewing properties and its behaviour in the seam.
3. Abrasion resistance. This is the ability of a thread to withstand seam abrasion in wear but the thread must also possess good abrasion resistance during sewing.
4. Sewability. Only an optimum combination of the above thread characteristics will give good sewing performance.

10.6.5 Thread types

Two of the most important types of thread are

– continuous filament polyester
– continuous filament nylon 6.6

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Continuous filament polyester

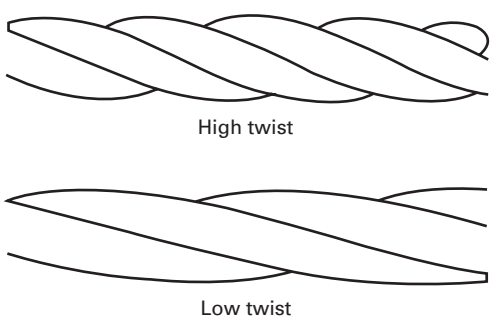
Polyester threads are characterised by their high tenacity and high abrasion resistance. Polyester has excellent resistance to weathering and is particularly suited to situations where prolonged exposure to acidic conditions is common. Individual yarns may be composed of 50 or more filaments. The advantages of these threads are: high strength level; good extensibility; good flexibility; and a smooth appearance.

Nylon 6.6

Nylon 6.6 has outstanding mechanical properties and makes the most suitable thread in many sewing applications. These multi-filament yarns are weight-for-weight stronger than steel and are very pliable. Their advantages include: high tenacity; excellent recovery; high abrasion resistance; high flex resistance; and resistance to alkalis. The high tenacity of nylon makes it ideal for use in many industrial applications where a high strength-to-weight ratio is an important prerequisite. High abrasion resistance is necessary for the thread to withstand the demands of the sewing operations and to create a durable seam. Bonding improves abrasion, reduces heat damage and resists untwisting, particularly on twin-needle and multi-directional machines.

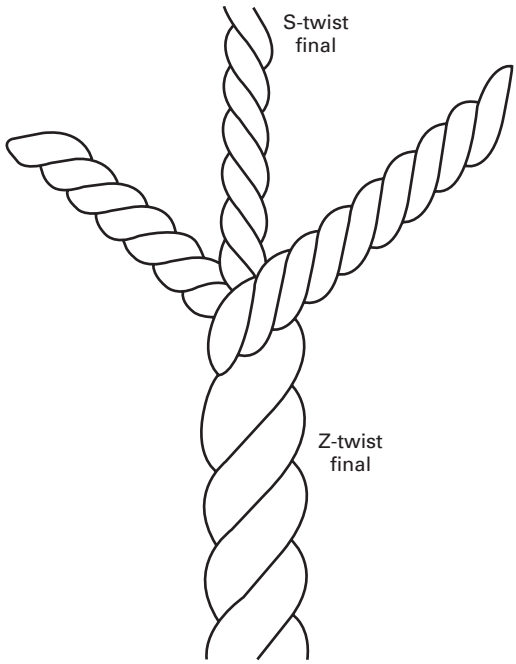
10.6.6 The twisting process

The twisting process is really the heart of thread manufacture (Fig. 10.10). It is this process that forms the sewing thread. All other processes affect the characteristics of the thread in some way, for instance dyeing adds colour, finish improves performance; but it is at the twisting stage where the thread is actually produced. Too much twist ('high twist') compounded as the thread is drawn from its package (Fig. 10.11) tends to snarl or 'knot' the thread especially around the thread guides of the sewing machine, this is known as

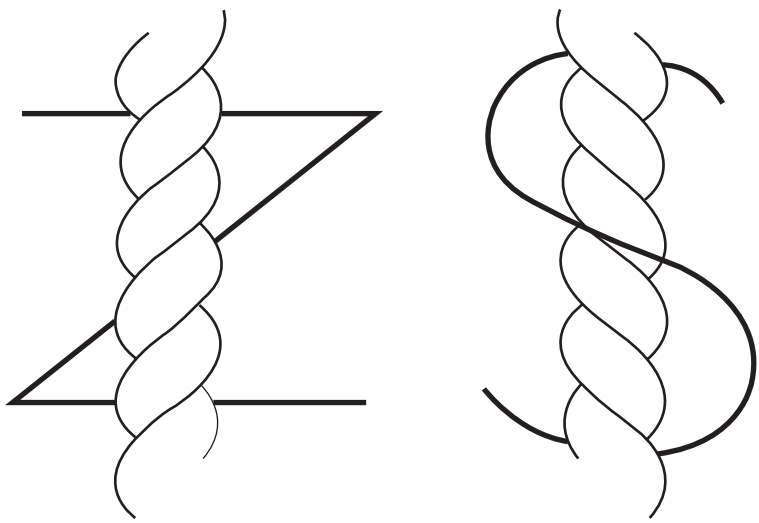


10.10 Twisting of the threads.

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10.11 High and low twist.



10.12 Z and S twist.

'twist liveliness'; not enough twist ('low twist') can cause fraying, and thread breakage and poor loop control during sewing. The twist of any thread can either be in the clockwise direction (S or usual) or anticlockwise (Z or

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reverse) direction (Fig. 10.12). The direction of twist must suit the action of the sewing machine. The 'Z' twist is now used on most sewing machines whereas 'S' is used for specialised operations on certain sewing machines and is predominantly used for hand sewing.

10.6.7 Thread selection

Before selecting the thread type, it is imperative that the particular seam type requirements are clearly understood. Seams can be defined as functional seams (joining parts of the fabric plies together) or decorative seams (used to enhance the design). It is essential that threads used in functional seams are strong enough to withstand the wear of the intended end use.

10.7 Advances in sewing-machine automation

Sewing machine automation is a process by which the processing of a product is achieved with little, or no human intervention. However, there are very few examples of machine automation within the sewn-products industry, particularly in the clothing sector. Therefore, this section will focus on, what is more accurately described as mechanised and semi-automated equipment that is used extensively with the clothing sector and will discuss the advantages and disadvantages of the automation of apparel production.

10.7.1 Advantages of sewing-equipment automation

Automated sewing production does have significant advantages in that:

- since the machine is performing the tasks, operator fatigue is reduced or eliminated;
- a reduction in labour costs can be achieved;
- production is more streamlined and efficient;
- reduced human intervention improves the consistency of product quality.

The invention of the electronic positioning motor, combined with the advances in electrical engineering and pneumatics technology, have enabled devices to be developed that enable, for example, automatic foot lifting, and automatic back tacking and stitch counting. All of these mechanisms have helped to reduce operator fatigue by removing the strain on the limbs that occurred when operating the mechanical equivalents of these devices.

10.7.2 Disadvantages of sewing-equipment automation

Full automation is still a long way from reality in clothing production. The factors that contribute to this are outlined below.

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1. The actuators used in automated equipment cannot replicate the dexterity of the human hand.
2. The flexible structure of textiles makes them more difficult to handle when sewing.
3. Textile materials tend to stick together and can be difficult to separate.
4. Production flexibility is more difficult with regard to changing over to new styles/products.
5. Products: fashionable variety, small number of pieces and short delivery times.
6. The range of materials and their characteristics such as low bending resistance, surface structure and thickness.
7. The complexity of sewing technology: manual change of top and bottom thread, visual monitoring of the processes.

There is also a social cost in that automated production plants require less labour than factories using conventional technology; therefore staff reductions can lead to more unemployment, particularly in developing countries.

10.8 Semi-automated sewing equipment

The original fixed-cycle machines have been developed into semi-automated technologies that sew a programmable distance and pattern. These machines are commonly called mechanised machines. Examples of these are: buttonhole machines; button sewing machines; bar-tacking machines; spot-tacking machines; and profile sewing equipment. Figure 10.13 shows an electronic buttonholing machine that allows for different types and lengths of buttonholes to be programmed into the machine for different types of products and buttons. Figure 10.14 shows an electronic button sewing machine consisting of a hopper that contained the buttons. The machine allows for different sizes and specifications of buttons and can be programmed to alter the sewing of the machine accordingly. Figure 10.15 shows an example of a mechanised bar-tacking machine, the stitches on this machine can be altered but only by mechanical means using a spanner on the stitch-adjusting leaver. Figure 10.16 shows an example of a mechanised blindstitch tacking machine used in the tailoring industry for attaching shoulder pads to the insides of ladies' and men's jackets.

The development of these machines has helped to revolutionise the efficient manufacture of clothing and are much more accurate than producing these stitches by hand.

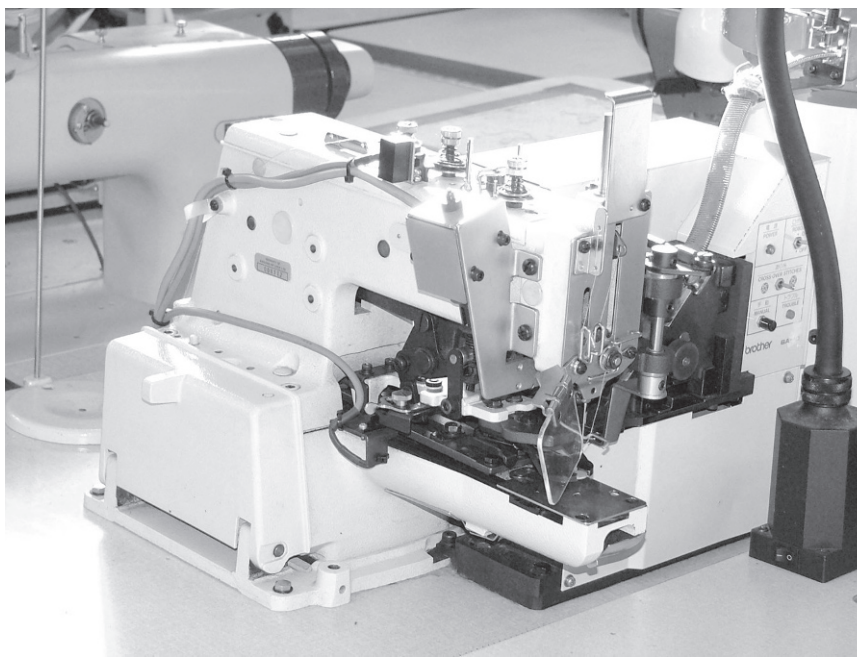
Profile sewing equipment

Profile sewing machines (Fig. 10.17) can be classed as a cross between mechanised and semi-automated machines. They generally have bigger work

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10.13 Electronic buttonholing machine.



10.14 Electronic button sewing machine.

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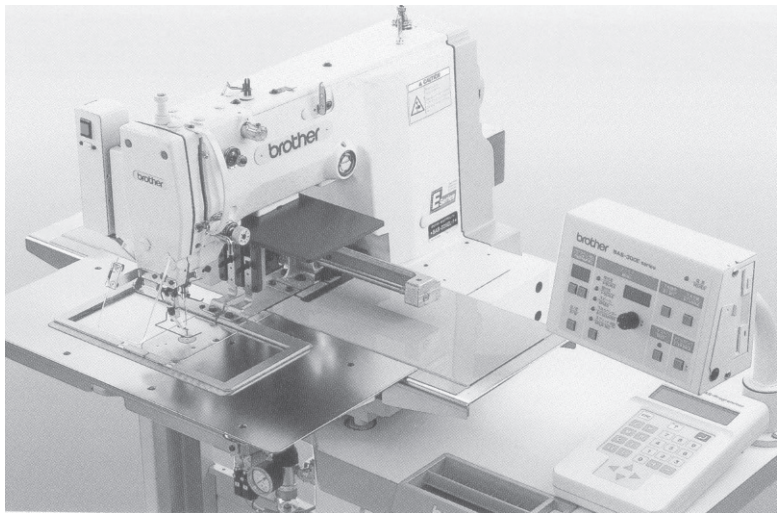


10.15 Mechanised bar-tacking machine.



10.16 Example of a mechanised blindstitch tacking machine.

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10.17 Profile stitching machine used for sewing decorative stitches on pockets.

stations and can complete a wider range of tasks than their mechanised counterparts. Profile sewing machines usually have the following characteristics:

- the fabric is usually controlled by a template and a jig;
- the material is fixed in the jig;
- the outline of the template guides the sewing operation;
- this type of equipment allows the accurate and repeatable production of components having very consistent quality at increased production rates.

Examples of where this type of machine is used include, for example, sewing patterns decorative stitching on pockets – usually on single plies of material placed under a clamp or a jig.

10.9 Machines using computer numerical control

Some machines are controlled by computers that use stepper motors to control the feeding process. Here, as with the mechanised and semi-automated machines, the feeding of the fabric takes place by the movement of the clamp holding the material. The movement of the clamp involves a sequence of movements converted into x and y co-ordinates. These co-ordinates are used by a computer program during the sewing operation; the program continuously delivers the x, y co-ordinates to servo motors acting either on the material or on the sewing head. Typical examples are embroidery machines

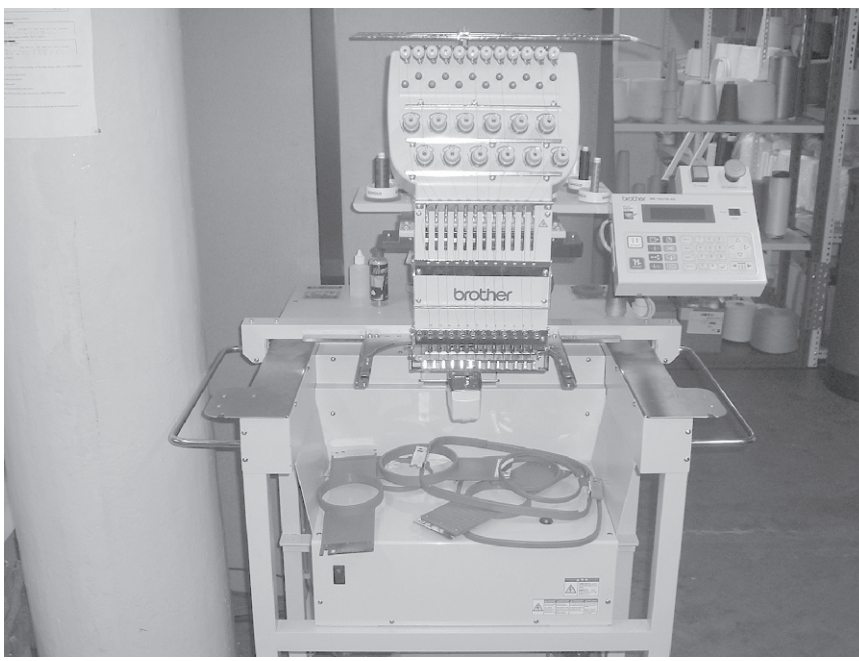
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where precise control is needed in order to control the stitching operation (Fig. 10.18).

10.10 Future trends in clothing technology

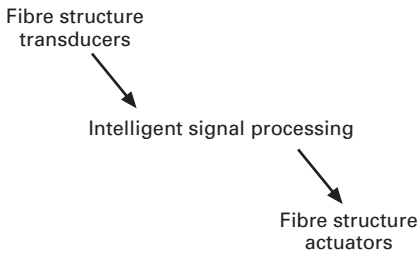
The evolutionary pathway of garment construction has progressed from its origins in a prehistoric epoch to the multi-billion industry that it has become today. The first generation of textiles were used for protection against the environment, to act as a barrier between the skin and the environment. The next revolutionary step was the creation of knowledge about the coloration of fibres and fabrics; these colours were initially expensive and only the rich could afford them. These garments represented an image and the concept of fashion was born. Because of modern methods of production, fashion has become more affordable, so much so that the latest trend has been in fast fashion, garments that are worn for a short period of time and then discarded in favour of others.

All of yesterday's textiles and garments have been passive in that they are unable to adapt to environmental changes. Future products, however, will be able to adapt to the environment. Products are being developed that use smart, intelligent fibre structures, the core elements of which are fibre structure transducers, intelligent signal processing and fibre structure actuators

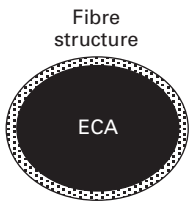


10.18 Embroidery machine.

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10.19 Diagram of the core elements in intelligent fibre structures.



10.20 Diagram showing the electro-conductive area (ECA) within the fibre structure.

(Fig. 10.19). Fibre structure sensors – which consist of strain gauges, switches, displacement transducers, electrodes and temperature transducers – create electrically active fibre structures. The simplest way of creating these fibre structures with significant electrical properties, is to incorporate conductive elements (Fig. 10.20) into the structure. The electro-conductive area (ECA) is created using electro-conductive fibres/yarns. These can be: metal yarns (monofilament); metal deposition yarns; metal yarns (multi-filament); carbon fibres and yarns; or conducting polymeric yarns. Stainless-steel yarn (Fig. 10.21) and spiral wound silver yarn are useful examples of yarns that are used in structures of this type. Strain gauges are being developed for respiratory measurements; these are knitted into garments and are capable of measuring blood pressure and heartbeat functions.

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10.21 Stainless steel yarn.

The world of textiles has advanced beyond recognition in a relatively short space of time. Advances in electronics and fibre science are enabling clothing production engineers to develop advanced products using smart technologies. Garments can now react to your body – whether it is to keep you warm, keep you healthy or even check your bank balance. The development of clothing products looks certain to become more reactive from now on, well into the future.

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11

Digital printing of textiles for improved apparel production

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11.1 Introduction

This chapter will focus on the technical and creative potentials and limitations for working with digital textile printing technologies in apparel production. Starting with a brief comparison of digital textile printing and traditional printing processes, the chapter describes the technology, characteristics specific to inkjet textile printing, and the design potentials and limitations. It then addresses how digital textile printing can be used to enhance apparel production, highlighting some innovative applications of the technology that take advantage of its capabilities. The chapter concludes by exploring future trends in the technology and by suggesting further resources for investigating its potential.

11.1.1 Principles of digital printing/comparison with traditional methods

Digital printing has had a long and sometimes difficult relationship with apparel production. The ability to print disperse dyes to paper digitally and to use the heat transfer/dye sublimation process to transfer an image directly to (mostly synthetic) cloth has existed for over 20 years. This chapter looks at more recent advances in digital technologies and textile-specific inks that allow for the direct digital printing of textiles, specifically through the use of inkjet printing technology.

The variables in direct digital printing of imagery to cloth using inkjet technology are so great that if the same print design were digitally printed on a variety of different printers using the same type of inksets and fabric, the end results could vary widely. Factors such as environmental conditions, ink properties and print head construction can cause results to vary from day to day using exactly the same printer and inks. To achieve consistent and appropriate outcomes for apparel production requires knowledge of fibre and fabric structure, preparatory and finishing processes, and ink/dyestuffs,

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together with a solid understanding of the printing technology, colour management systems and raster image processors (RIPs). This chapter highlights the potentials and limitations of using direct digital textile printing in garment production and showcases some innovative applications of the technology.

Much of the technical information about digital textile printing can be found in more detail in other publications, such as my chapter in *Total Colour Management in Textiles* (Campbell, 2006) and the full text of *Digital Printing of Textiles* (Ujiie, 2006) offered through Woodhead Publishers. This chapter will therefore briefly reiterate the technical information and description of the design potentials and limitations of direct digital textile printing, and will then focus on key projects and case studies of applications of the technology to apparel production concepts.

> The choices of printers, software and solutions available on the market can be confusing. Users of the technology must evaluate a broad range of software and ink/dye solutions designed to support particular devices. How can the user best evaluate which components interact with each other to produce optimum results? A solid understanding of the printing technology as well as the software and systems that run it must be balanced with a clear picture of the role of the end output. (Campbell, 2006)

Brief descriptions of the two prominent inkjet printing technologies are given below.

11.1.2 Thermal drop-on-demand (DOD) inkjet

Thermal inkjet print heads use heat as the mechanism for forcing the ink through very small openings. The ink is heated in many small chambers producing bubbles of water vapour, which increases pressure in the print head forcing an ink droplet to be ejected towards the surface of the fabric. The goal for developers using textile dyes is to minimize the heating while maximizing the droplet formation, to reduce premature reaction of the dye. Most thermal inkjet printers (sometimes also referred to as 'bubble jet') use water-based inks and are good for low-volume printing. High resolution is attained by using small and variable drop sizes. The performance of thermal print heads over their lifespan follows an exponentially decreasing curve, so it can be difficult to attain consistent quality over time. Consistency can also vary due to the inks being heated up to nearly vapour level to create the ink droplet, which can cause some of the colourant or binder to be deposited on the print head resistor (Tincher, 2003).

The use of DOD thermal heads in digital textile printing can have both advantages and disadvantages. The relatively inexpensive cost of the thermal heads helps reduce the overall cost of the printers, which often have separate

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ink cartridges for each colour printed. The individual cartridges, which hold a small quantity of ink, can be easily connected to bulk-ink tanks that are refillable during printing. If one colour fails or clogs the cartridge, then that specific cartridge can be removed and replaced quickly without having an impact on any of the other print heads. Ink developers producing dye-based inks for fabric have to modify the dyes to be more resistant to lower level heat so that they can successfully flow through the thermal print heads and still bond to the fabric.

11.1.3 Piezoelectric drop-on-demand inkjet

Piezo print heads work by the following principle: droplets of ink are mechanically ejected from a nozzle in the ink chamber when an electrical current impulse activates a piezo crystal, causing it to expand and eject an ink droplet. Since the process is a mechanical one and does not require heat, it can be very precisely controlled (Epson, 2004). The advantages of piezo technology are that the heads are more reliable and have a longer lifespan than thermal heads. They are good for high-volume printing. Piezo heads are slightly more capable of using a wider variety of inks and pigments, because the head can be created entirely out of inert ceramic materials. The performance of DOD piezo heads over time is mostly level with a rapid drop-off. The greatest disadvantage of piezo technology is its cost; another disadvantage is that piezo print heads are susceptible to entrapped air, which can lead to misfiring nozzles requiring multiple head cleanings (Baydo and Groscup, 2001). The print heads are permanently mounted into printers and are not easy to replace if they do fail. Piezo DOD printers are typically higher priced than thermal DOD printers.

11.2 Main advances in digital printing technology

11.2.1 Brief history of digital textile printing in the apparel industry

Direct digital textile printing has heen a relatively recent addition to applications in the apparel industry. Originally, it was primarily used for printing fabric samples and prototypes used in the product development process. Clothing design and manufacturing companies either housed a wide-format digital printer within their own facility, allowing for quick visualization of textile samples or they sent their designs to be printed at digital textile printing service bureaus such as the Centre for Advanced Textiles (Glasgow, UK), Print Unlimited (Boxmeer, the Netherlands), RA Smart (Macclesfield, UK), First2Print (New York and Los Angeles) and Direct Digital Printing (Sydney, Australia).

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With the introduction of the technology to the textile and apparel industry there was initially such a focus on increasing print speeds to match traditional printing that a conceptual lag-time in applying the technology to production ensued. Recent advances in the technology have the potential to lead the way into a whole world of 'reflexively produced' designs. In March 2007, a Sydney-based company called Memjet announced the development of a new inkjet printer architecture that has the potential to further revolutionize the speed/cost relationship in digital printing. It is a scalable and modular print head and print engine system, that helps to compensate for the time spent in standard inkjet printing for the heads to traverse across the surface of the fabric (from selvedge to selvedge) to apply the printed image.

11.2.2 Characteristics and variables of direct inkjet printing

In order to use direct inkjet printing (DIJP) technology for fabric effectively, we must be able to conceptualize the printing variables that distinguish this technology from traditional textile printing processes. This section will expand on the physical and use-oriented characteristics of the technology.

DIJP does not require rollers or screens. It is a non-contact printing process; the print heads never touch the fabric, they merely eject the ink droplets onto the surface. As such it is inherently different from almost every other type of textile printing. It allows for the possibility to design without a repeat. DIJP eliminates major colour registration problems that are always an issue with roller or rotary-based screen printing. DIJP enables artists/designers to be more creative and provides for greater experimentation with colour and composition at much lower cost. A designer can realize their idea on cloth in a very short period of time and, if the design is not successful, they can return to the design process immediately, make modifications and print again to witness the results. From a textile printing production point of view, DIJP decreases machine downtime in-between designs. This has an important and profitable impact for companies producing strike-offs and samples. DIJP can lower the costs of short-run production, producing a greater variety of units with a faster cycle time, thus allowing manufacturers to be more responsive to the marketplace. This technology also virtually eliminates dye waste and, as such, is more environmentally friendly. It also enhances the opportunities for personalization and customization, allowing artists and designers to interface directly with the end consumer to address their personal preferences and interests. Because of these capabilities, DIJP holds the potential to tip the balance of textile print manufacturing back to more industrialized, higher labour-cost countries, while reducing the inventory costs that are currently incurred by housing the multitudes of screens and inks. Given that DIJP holds all of this conceptual potential, let us look more closely at the factors

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that must be accounted for in the day-to-day production of consistent and effective fabric prints.

As we have already addressed the print head technology, the physical and use-oriented variables to be discussed below will be: pre-treatment, dye/ink penetration, environment, post-treatment and continued care (Section 11.2.3); and printing width/fabric handling, print speed and features, print resolution, drop size, ink types/characteristics, fibre type and fabric structure (Section 11.3.1). Each of these variables will have an impact on both colour matching and colour permanence. The integration of RIP software, colour profiling and management issues will also be discussed (Sections 11.2.4 to 11.2.6).

11.2.3 Pre-treatment, printing and finishing requirements, advances and implications

Pre-treatment

The pre-treatment needed for the fabric will depend on the ink to be used (dye-based, reactive, acid, disperse, pigment). Many who are interested in entering the field ask, 'Is pre-treatment truly a requirement?' The answer is most probably yes if we want to achieve the right colour and improve the performance of the ink, and to maximize the fibre's chemical reaction with the ink (Locastro, 2001). Pre-treatments are applied to the fabrics specifically based on the fibre type and inkset that will be used for printing, and are not particularly standardized across the industry.

Environment

In order to maximize printer, fabric and dye efficiency, the environment in which the printing occurs should be controlled as much as possible. Reactive dyes require a much more humid environment to reduce clogging and maintain high levels of bonding to the fabric. This is not the case at all with pigments. Typically, the printer components run more efficiently in drier atmospheric conditions. Maintaining more consistent environmental conditions will help to ensure more accurate and uniform printing.

Substrate post-treatment

Fabric finishing is probably a necessity for creating production items. Depending on the pre-treatment, inkset and the purpose of the output, different post-treatment processes are required. Reactive and acid dyes require steaming for the dyes to bond to the fibre; disperse dyes require heat for sublimation. The two strongest reasons for post-treatment are to increase the colour gamut

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(many of the dyes display a wider gamut after steaming) and to improve colourfastness to light, crocking (rubbing) or washing.

Managing colour matching and consistency of digitally printed fabrics is *greatly* complicated by the post-processing requirements. Because acid, reactive and disperse dyes change colour and expand their gamut after steaming, colour profiling must be generated from fabrics that have been fully steamed and rinsed. Some of the colours that have 'popped', or become enhanced through steaming may be lost again during the rinsing process. For production garments, rinsing is a necessity to wash off any excess dye that has not been fixed during steaming.

Continued care of digitally printed cloth

As the digital textile printing industry becomes more developed in the production arena, there will become a need for more focused attention on the continued care issues with digitally printed fabrics. Although the overall performances of the acid, reactive and disperse dyes are thought to be similar to what they would be with traditionally printed fabrics, there are differences that could have an impact on their longevity. The nature of inkjet printing technology is such that very little ink is used per square metre of the fabric. Ink drops will predominantly soak only into the outer surface of the fabric after it has been printed, especially in tightly woven or pile fabrics. The dyes often do not penetrate the fabric completely. This means that digitally printed fabrics are more susceptible to colour loss from the wear of rubbing over time than they might be to colour loss from washing. Laundering and storage issues of digitally printed fabrics need to be further explored to inform the design and development stages of printing. Washing conditions and agents are related to consumer preference; colourfastness problems may be minimized by consumers' appropriate selections of washing conditions and agents. Therefore, in order to provide consumers with appropriate care information, it is necessary to examine how different washing conditions or agents affect colourfastness during laundering of digitally printed fabrics.

11.2.4 Colour management and raster image processing

Ensuring accuracy and uniformity

Profiling and testing is increasingly complex for using DIJP to produce wash-fast fabrics. Ensuring accuracy involves not only calibrating printers and monitors for the media, but also using consistent methods for steaming, rinsing and finishing the fabrics.

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Process colour systems

Looking at the different process colour printing systems will help in understanding the realistic colour capabilities and expectations one should have of these systems. CMYK is a 4-colour printing process using three subtractive colour primaries (cyan, magenta and yellow) with black. The colour limitations of CMYK lie in the difficulty of reproducing bright reds, greens and blues. The CMYK process is improved by including extra colours that can not be reproduced by dithering or mixing cyan, magenta and yellow. As a general rule, the greater the number of colours (not print heads) that are in a printer, the larger the gamut of colours that can be reproduced (Gordon, 2001). For example, a 12-colour printer with 10 individual colours and 2 light shades will provide a much larger colour gamut than a 12-colour printer using CMYK with light shades. It is important, however, to have a balance of colourants to light shades in order to eliminate visible dither. The inks determine the colour space, but the raster image processing (RIP) drives and manages those colours. Digital textile printers are developed, tested and marketed with the use of specific inksets in co-operation with ink vendors offering inks specially formulated for the textile market.

Defining and profiling colour

Components of RIP packages and colour management systems (CMSs) that should be considered are described below. The CMS and RIP software must be able to work together to create consistent colour from monitor to fabric. A good CMS should characterize input colour devices, colour displays and output colour devices by using software and a spectrophotometer to create a small data file in the form of a conversion chart, which is called a profile. The profile creates a conversion chart by cross-referencing information from the input, display or outputs' colour space and determining the equal value of that information in the CIE (International Commission on Illumination) L*a*b* colour space (a standardized colour reference space).

CMS and RIP software manage colour by creating profiles or characterizations specific to the printer, ink, fabric and any post-processing, such as steaming and washing. All of these variables have an impact on colour and each variation must be profiled to ensure accurate colour match. When a design is printed, a profile is selected based on the printer/ink/media combination to ensure that the colours in the original design match the digitally printed output.

Raster image processors

The RIP software is essentially a sophisticated printer driver that allows for greater user control in rasterizing the image (converting the data) for the

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printer. The RIP software must be written for the specific printers in order to take full advantage of the hardware capabilities. The RIP ultimately controls the printer and the colourant. In addition to colour management capabilities, textile-specific software is needed to handle print design images such as flat and continuous tone designs, separation files and files prepared for repeat printing. Important software features for DIJP include the ability to accept textile industry file formats from computer-aided design (CAD) and screen separation programs (such as CST, MST, PUB, GRT, SEP, SCN and XPF) The software must also be able to accept common graphic file formats such as TIFF, indexed 8-bit TIFF, PSD, EPS, AI, BMP and TGA. Print layout functions such as step and repeat, design colourways, colour chips, multi-image placement, scaling, rotating, spooling or batching are also desirable features. Specialized screen print simulation features of software such as DuPont's Colour Control and Management System (CCMS) are highly desirable if the digital output needs to match to screen-printed production yardage. The colour management and RIP software options available to the textile industry reflect a growing market acceptance of digitally printed fabric for proofing, sampling and short-run production.

11.2.5 Workflow issues

In order to further ensure accuracy and uniformity in the process of DIJP, design and manufacturing firms must employ people who understand computer integrated design tools, colour, fabric issues and the components to use with the printers. Employers must have dedicated people to work with equipment, and must be organized with all of the variables, digital and non-digital. An often neglected issue is the continued need for calibration of printers and monitors, which requires labour hours and down time for printing. Without consistently scheduled calibration procedures, maintaining colour accuracy can be quite difficult. In addition, because of the relatively small lots of fabric that are being pre-treated for digital printing, when printing to natural fibre fabrics it is very common for one lot to vary greatly from the next in terms of quality, absorbency and pre-treatment. This means that the user is likely to have to build or modify profiles of even the same fabrics from time to time.

11.2.6 Speed: the false motivating factor behind production advances in digital textile printing

One of the strong misconceptions about the role of digital textile printing technology when it was originally introduced to the market was that it could potentially be a technology that would replace production screen printing. This might have been partly due to the lure of what seemed to be the ease of generating print designs digitally (which had already become the industry norm) and

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outputting them directly to the printer without creating colour reductions and separations. This implied a potential time-saver in the 'printed textile supply chain'. This perception relied heavily on a manufacturing perspective for product development. Along with the desire to reduce costs in manufacturing, it tricked early adopters into believing that the combination of time saved in development and manufacturing of the printed textiles combined with the relative speed of the printers, could usher in a new technology for large-scale print production. As a result, printer developers spent a great deal of energy trying to engineer the printers to print (at the same or similar quality) more quickly, so that print speeds could rival existing screen print production.

While the increased printer speed was a valuable feature, it was by no means the 'holy grail' of digital textile printing production for a few key reasons. Firstly, the technology offers a completely different method of printing textiles, which is unique in its application of imagery to cloth. DIJP is essentially the only non-contact image printing process for fabrics. This means that *any* type of fabric can be used as a printed surface, provided it can be fed through the printer and is appropriate for the inkset being used. Fabrics can be relatively easily changed, almost as quickly as the print design can be changed on the machine. Secondly, the average footprint of a digital inkjet printer requires only a fraction of the floor space needed to house a production rotary screen printer. So, even if only one design were being printed on one fabric for thousands of metres, it could potentially be more cost-effective to simply purchase and run more inkjet printers. Some companies have taken advantage of this philosophy, notably Hangzhou Honghua Digital Technology Stock Co., Ltd. in China.

This line of reasoning still only considers digital textile printing from a mass production point of view; however, from a design, product development and customization point of view DIJP has far more potential to have an impact on apparel production. Print speed is nearly irrelevant when a company is processing orders for single items or short-run production. When a consumer realizes that a company can provide them with the ability to customize imagery for their own specific garment desires, and feels as though they have actively engaged in the experience of creating the product, then the perceived value in the product is shifted to include the entire customization *experience*. The true optimization goal then for businesses effectively employing digital textile printing in apparel production lies in *flexibility* in ordering, *response time* and *processing small batches* of printed fabric.

Large-scale production-style printers versus multiple small, higher quality printers

Some digital textile printer developers have focused on creating solutions for large-scale production-style printers to compete for production orders in

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digital printing. Regianni have created the Dream® Machine and Dupont the Artistri® to print fabric digitally in large print runs. These machines have been placed and are filling a certain role in production printing for garments, but more commonly they are being used for the home textiles market to generate bedding, curtains and tableware textiles. The most innovative applications of the technology for apparel tend to be coming from small- to medium-scale enterprises who are taking advantage of the flexibility that medium-scale digital textile printers like the Mimaki TX3 can offer. The return on investment of printers in the high-resolution/smaller footprint range is often much more rapid.

The next section will delineate the key features of DIJP that influence the design and production capabilities.

11.3 Design potential and limitations of digital textile printing

11.3.1 Physical factors of digital inkjet printing that affect the design potential

Printing width/fabric handling

The maximum printing width of wide-format inkjet printers for textiles ranges from 36 inches (91 cm) to as much as 126 inches (320 cm). The greatest constraint on fabric width lies with how the different printers handle the fabric. Since many of the early printers that were introduced to the digital textile printing market were modified graphics/paper printers, they often require the fabric to be paper-backed for stability and then fed through the printer in the same way that a roll of wide photo paper would be. This adds cost to digitally printed fabrics.

Subsequent printers that were developed for the DIJP market incorporated fabric handling without paper backing. Features such as: 'edge trackers' that automatically track the edge of the fabric and clip the print image so that ink waste and mess was avoided; web handling; tension/feed adjustments; 'selvage edge handlers' that allow fabric with fringed selvage to be printed without causing the print head to be dragged across the fringe yarns; and eventually 'sticky belt' feed rollers proved to be far more efficient for textile-specific printing needs than those of the more standardized printers. These are the key features that continue to be implemented and improved with the more recent printers released to the market for fabric printing.

Print speed and features

Five key features affect print quality and quantity of ink application to cloth. These are printing speed, print head movement, printing passage, ink placement

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and head height. Printing speed is controlled primarily by the mechanism by which the print heads are mounted to a carriage and the system for traversing the carriage back and forth across the width of the fabric. The heads will most likely be positioned on the carriage so that they are staggered along the length of the fabric. This allows for multiple colours to be applied during the same print pass. Printing speed is greatly affected by whether the printer is capable of bi-directional printing in the print head movement. Bi-directional printing applies ink both as it travels across the fabric and as it returns. These settings can often be adjusted on the printer to improve or reduce the quality or ink lay-down based on the user's needs. To allow for the quantity of ink necessary to create the proper hue and saturation on the fabric surface, most printers have multiple print passes of the same ink drop arrangement over the same area of fabric. The physical mechanisms for creating precise droplet formation and placement on the fabric surface are a function of both the print head construction and the speed at which the carriage is moving. Software interpolation governs the pattern in which the ink droplets will be arranged. To allow for the printing of thicker or textured fabrics such as pile weaves, some printers are able to adjust the height of the print heads or platen.

Resolution

The way in which the RIP software handles resolution is very important, but it is the print head technology that governs the geometric resolution (300 dpi, 600 dpi) versus the perceptual resolution. A good RIP package will allow full control of dot gain adjustment and will have the ability to control half-toning. All of these adjustments will be heavily influenced or limited by the structure of the fabric that is being printed. Higher resolution allows for smaller drop size, enabling more accurate tonal control for images with large ranging gradient fills.

Drop size and formation

Smaller drop sizes allow the print to capture fine details, reduce graininess and integrate finer tonal curves. The cleaner the droplet of ink, the less likely the occurrence of satellite drops, which can reduce the clarity of the image. The drop pattern is controlled by the firing of the print head and is affected by the viscosity of the ink.

Ink types and characteristics

Ink factors that will affect usability include: (a) the molecular size of the colourant; (b) the colour gamut attainable with the dye class; (c) the stability

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of the ink to resist precipitation so that it can have a longer shelf life; (d) viscosity; (e) the ink's ability to be de-gassed so that bubbles will not form in the print head; and (f) the ink's colourfastness (wash fastness, light fastness, crocking). Inks to be used for digital textile printing will vary based on fibre type, pre-treatment, finishing and end-use. Pigmented inks require a binder to hold the colourant to the fabric. In inkjet printing, the binder must be applied either in the ink, by separate nozzle, or by pre-treating the fabric with a receptive binder. For production fabrics, the correct dye class must be used to attain effective wash fastness. With the exception of some pigment inkset solutions, almost all fabrics will need to be pre-treated with a small amount of coagulant to avoid wicking and spreading of the ink droplets before drying on the fabric.

Fibre type

In addition to fibre content, absorbency, wicking properties, surface structure and length of the fibre will affect how the colourant is applied. The length of the fibre contributes to the quality of the yarn and thus the smoothness of the fabric. Generally in DIJP, the smoother the fabric, the more accurate and detailed is the image that can be printed.

Fabric structure

Fabric structure will also affect the clarity and colour richness of a digitally printed image. Wicking can also be enhanced or subdued depending on the fabric structure. Weaves with long floats like satin tend towards higher levels of wicking, plain weave fabrics or knit minimize wicking. If the fabric structure is very bulky or uses a great deal of yarn, as is the case with knitted fabric, it will be more absorptive and require greater amounts of ink/dye to be printed. The denser the weave or surface structure, the greater the likelihood of increased surface tension.

11.3.2 Designer approaches enabled by the technology

In this section, we will elaborate on the design issues and potentials/limitations of the technology for digitally printing to fabric. These issues are ultimately tied to the designer's role in conceptualizing the end product. The following are issues that have been determined to have an impact on the design approach: (a) the use of repeat designs versus non-repeating image creation; (b) the use of photo-realistic imagery; (c) the potential for greater variations in size and scale; (d) the possibility of creating more producible engineered digital three-dimensional forms (Ujiie, 2003; Parsons and Campbell, 2004). In addition,

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the potential for the technology to fully engage the 'co-design process for mass customization' will be discussed.

Use of repeat designs versus non-repeating image creation

Using traditional textile printing processes the physical size of a print design is limited to the size of the screen or roller. With direct digital textile printing, it is possible to develop large-scale print designs in which the elements of the print design are never repeated.

Use of photo-realistic imagery

In creating digitally printable imagery for textiles, the designer can incorporate the use of high-resolution images to push the limits of photo-realistic printing. Photo-realism opens the possibility for the use of multi-layered imagery, ghosting effects, an unlimited use of colour, extreme tonal images, surface/texture simulation, digitally created effects and a number of possibilities that are not cost-effective or even possible to produce through traditional printing methods.

Variations in size and scale

Digital printing allows the designer to quickly print out the same image at different scales to test the visual impact, or to add variation to a textile collection without having to design multiple images. This requires a great deal of time and money if carried out using traditional printing techniques. Designers can also use digital capture technology to obtain high-resolution images of the microscopic world and transform them easily into huge-scale prints, with little loss of visual quality.

Engineered, digital three-dimensional forms

Apparel, furniture and/or sculptural pieces can be designed for digital textile printing in which the imagery is continuous around the form. Through the integrated use of textile and apparel design software, printable designs can be tailored directly to pattern pieces for a garment. By engineering the textile print designs into each garment pattern shape, print designs can become more personalized and body specific. The image-filled pattern pieces are all that are printed to the fabric, leaving all areas of the fabric that are not used in the garment unprinted, thus saving ink. These pieces can simply be cut out and sewn together to create a finished garment (Parsons and Campbell, 2004).

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Customization and personalization through a co-design process

> Co-design processes allow a customer to interact with a sales person or consultant to (a) choose an individualized combination of product style, fabric, color, and size from a group of options, (b) create the customer's own unique design based on his/her preferences, and (c) achieve personal size and fit using physical body measurements or body scanning. (Lee *et al*., 2002)

Digital textile printing allows for a multitude of possibilities in applying imagery to fabrics, but end consumers are not always aware of them. As such, research conducted by Lee *et al*. (2002) on the acceptance of mass customization of apparel, demonstrated that consumers preferred to engage in the co-design process to customize. Through developing innovative online interfaces or providing in-store customization opportunities, DIJP can be used to engage very responsively in the experience of customizing garments to include manipulated image combinations, or even incorporate their own photographs and/or digitally captured content.

11.3.3 The concept of digital as 'perfect' – addressing issues of accuracy, uniformity and consistency

In managing the commercial service at the Centre for Advanced Textiles, we have encountered on numerous occasions a misconception about digital textile printing that can be very disturbing for companies providing digital fabric offerings in their garment collections. We have loosely described the phenomena as 'thinking of digital as perfect'. It is true that, comparatively speaking, one of the major advantages of designing for print using digital design tools is that it can provide a degree of precision that is often much higher than creating the same imagery through analogue technologies. This, however, is not the same as perfection. Many customers assume that their imagery should look exactly the same as it did on screen once it has been printed to the fabric. There are many factors that make this impossible. The physical limits of the colour gamuts that are possible through dye- or pigment-based inksets are never likely to be able to fully match the much wider gamut that can be viewed through light on a computer screen. Add to this, the very nature of natural fibre fabrics to be different from lot to lot, the pre-treatment of the fabric (which has potential for flaws and decreasing effectiveness with age), the environmental conditions during the printing process and post-treatment (which requires steam, pressure, specific timing, laundering and ironing); what results is a high change of mismatches and inconsistencies. The only stage that is nearly perfect is the actual process of printing the fabric, yet even still there is potential for clogged print heads and banding, or other flaws in the lay-down of the ink that can become visually apparent.

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Most individuals who come from a background in textiles and clothing are fully prepared to take these issues on board and incorporate them into the process of working with digital printing, but because the technology is so accessible and has its 'cultural' roots in graphic printing to paper many of the customers who are producing production garments are not actually from the textile and apparel design field! Additionally, customers who are familiar with having their designs translated for screen printing are often surprised when the clarity of their work is not necessarily improved through the application of digital printing. This is often because they are attempting to translate imagery that was optimized for one type of (analogue) printing technology and then replicate it on another (digital) technology. If we were to take highly complex imagery that had been intentionally designed to be in ghosted layers, in and out of focus, with some hard edge imagery and some very soft gradient imagery that printed very well digitally, and then use that same imagery to create screens for rotary printing, we would rarely expect the same results from the two technologies.

11.4 How digital textile printing can enhance production in the apparel industry

11.4.1 Recognizing the purpose of the end output when using digital textile printing as a production tool

This section will include an analysis of the ways in which the textile and apparel industry, as well as independent/collaborative designers, are using the technology for apparel production. The approaches differ depending on the end use. Many artists have adopted the technology to create one-of-a-kind or limited-edition artworks. Small-scale companies such as Gild the Lily, based out of Providence, Rhode Island, print scarves and garments on demand as they are ordered from their pre-designed choices on the Internet. Recently, companies such as Direct Digital Printing in Sydney, Australia, have begun to focus on collaborative, production-quantity, digital printing for the interiors and apparel markets. To get the right output, digital textile print providers must choose the right software, integrator, printer, ink, fabric and RIP and the right studio. For every given end product, there will be different requirements for speed, quality, colour matching, colourfastness, etc.

Production

Production-style printing can be approached from a number of different angles, but the key similarity is that the end product needs to conform to the ultimate consumer's expectation for style, innovation, usability, purchaseability

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and serviceability. Possible output for short-run production could include products used for marketing, sales or promotional activity. One-of-a-kind products such as garments sold in speciality boutiques, costumes for cinema or theatre productions, or artwork to be displayed in galleries would also qualify as production-style printed media. In the more recent months, a few companies across the world have started providing production-printed yardage to the apparel and interiors industries by using printers like the DuPont Artistri® 3210 or the Reggiani Dream® Machine.

11.4.2 The transition from sampling to production, from prototype to product

As a result of the continued growth and acceptance of the technology, quick response and short-run production will become more pervasive and will help to shift some of the design focus away from large-scale production fabrics. As consumers become more aware of what is truly possible with digital textile printing, there will be an increased move towards customization and personalization. Developments in the larger-scale production printers like the Reggiani Dream® Machine will help mills to become more effective with agile manufacturing. Digital textile printing may soon become combined as one component of the various production steps of print, cut, sew that are becoming mechanized for on-demand mass customization practices of marketing. In addition, digital textile printing will continue to provide a simplification of the path from apparel specification through to the manufacturing of finished product and, at the same time, will help to meet the trend of vast customization (the ability to customize a range of products in a variety of substrates: textile, paper, metal, glass, etc.).

11.5 Applications

11.5.1 Research and case studies in direct inkjet printing production

This section describes a few innovative applications of digital textile printing for production-focused garment design, including research into the production capabilities of digital textile printing for mass customization. I began working directly with wide-format DIJP in 1998. As I worked to test the limits of the new technology and evaluate the output for visual quality and colourfastness, I also developed a plan for how to approach the testing of the successful uses for DIJP in the textile and apparel industries. The opportunities that DITP provided for developing engineered prints in garment design soon become apparent.

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Collaborative designers Jean Parsons and J. R. Campbell

In late 1999, I began collaborating with Dr Jean Parsons at Iowa State University to create complex engineered, digitally printed garment concepts. Our initial collaborations were aimed at exploring the edges of the technology to generate garments that would not easily be adopted into a larger-scale production plan, but could perhaps function as inspiration for what was possible with the technology. Figure 11.1 shows an example of these collaborations.

In January of 2003, Dr Parsons and I were commissioned to create a custom-designed digitally engineered and printed inaugural ball gown for the First Lady of Iowa, Christie Vilsack. She immediately became enchanted with the idea of using photographic imagery of stained-glass windows from her own home (the Terrace Hill mansion and governor's residence) in the gown. This visual connection to her living experience, to the connections it made between her and the social and political history of Iowa, became very compelling to her, and provided an excellent publicity platform for showcasing the potentials of DIJP for apparel production. When the design was finally printed and finished, it fitted very well, even given the technical difficulties with the skewed grain of the silk satin fabric; Mrs Vilsack was thrilled. The project gained such publicity that we were interviewed on CNN Headline News (13th January, 2003) while printing the gown. What was more interesting though, was that Mrs Vilsack used the commissioned project as a way to



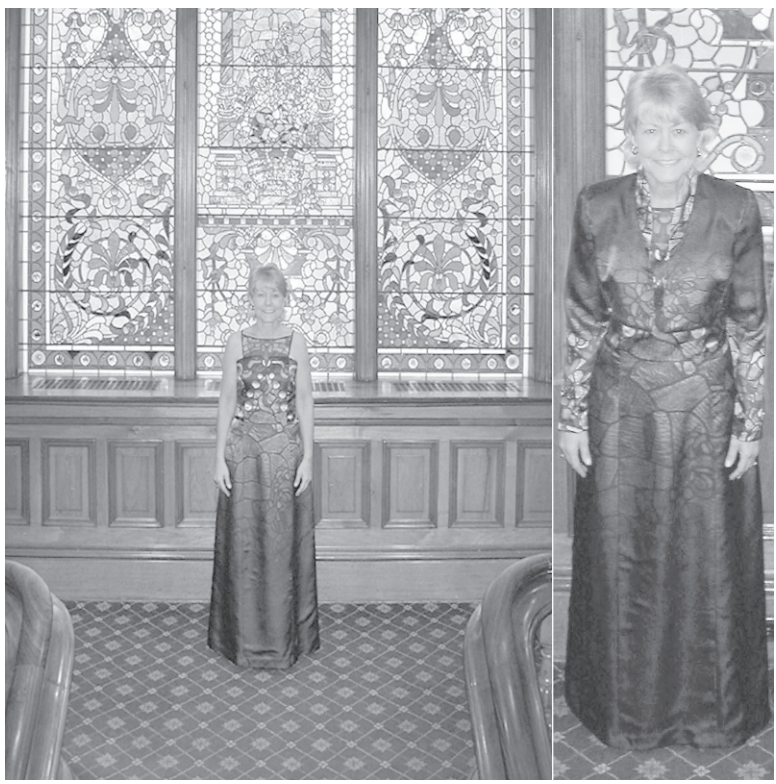
11.1 Summer. Digital engineered and printed jacket by Jean Parsons, J. R. Campbell and Susan Strawn. Silk broadcloth, silk gauze and strip-knitted silk organza.

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demonstrate the potential for Iowa's economic growth through innovative application of digital tools accessible for small to medium enterprises. Photographs of the final silk gown and accompanying jacket are shown in Fig. 11.2.

The 'Digikids' mass customization experiment

By 2001, there had been a great deal of speculation published on the potential for digital textile printing to enhance apparel customization, but few working examples of the application had been tested and reported. As a result, I led a research project that our team dubbed 'Digikids: Creating Customized Children's Clothing'. The purposes of this research were to examine the application of digital printing technology to the co-design process of mass customization, and to analyze both the marketing of digitally printed garments through an Internet retail environment and the success of the final garment in meeting consumers' needs.

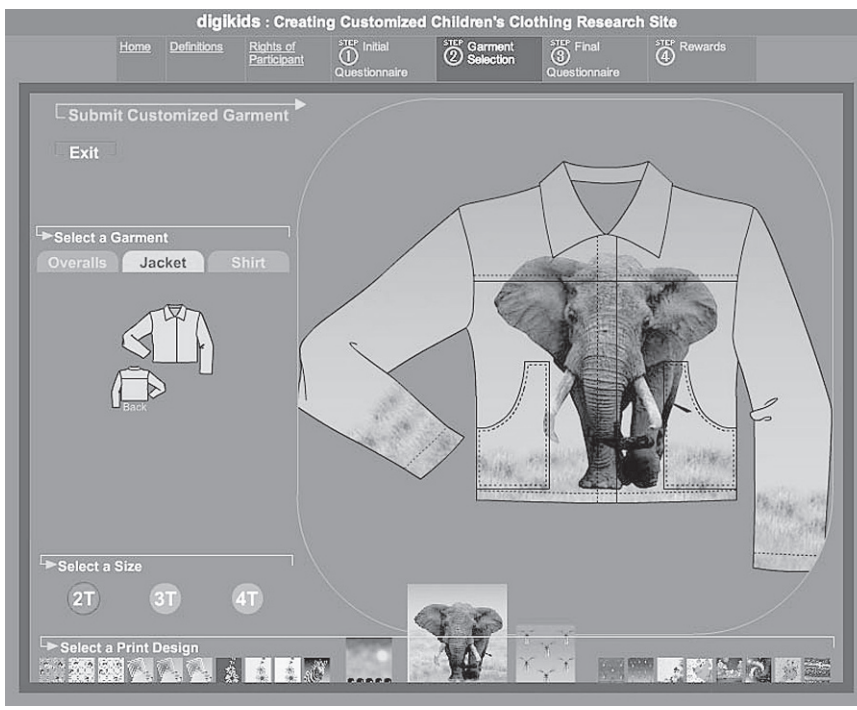


11.2 Vilsack inaugural ball gown. J. R. Campbell and Jean Parsons, 2003. Digitally printed silk satin and silk gauze.

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The project collaborators created a series of digitally printed textile designs and children's garment prototypes for use in the co-design scenario. Screenshots of the Digikids website interface can be seen in Fig. 11.3. These were 'marketed' through an original web interface. In providing customization options, we strove to minimize the total number of variations while offering the greatest variety of output possibilities. We then tested the participants' degree of satisfaction with the options presented. A purposeful sample of mock-consumers selected specific garments and surface design features, then mixed and combined the components to create their own customized garment. Once the sample group participation was concluded, the research collaborators produced a subset of the garments chosen by the consumers. For the web interface, we tested expectation and satisfaction with regards to:

- perceptions about digital textile printing;
- degree of complexity in the customization website design/interface;
- fabric choice;
- garment style choice;
- customizable features;
- price range;



11.3 Digikids mass customization online design interface. J. R. Campbell, Jean Parsons, Suzanne Loker and Mary Lynn Damhorst.

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- timeline to complete customization online;
- timeline to receive completed garment.

In testing expectations before the customization process, the participants:

- expected the process would be fun;
- expected to be able to select the garment colour and fabric print that they would like;
- expected to be able to select a unique style first and then expected to be able to select the correct size.

Once they engaged in the process, they:

- tended to prefer the more accessible imagery with recognizable motifs;
- more commonly chose the T-shirt concept over jacket or overalls (64 out of 158 garments customized);
- most commonly chose the photographic floral designs.

All 13 of the print designs offered were selected at least once out of our group of approximately 200 participants, representing a fair diversity of selection from a small group of consumers. This distribution of selection gives strength to the 'Long Tail' marketing strategy introduced by Chris Anderson (2005) in approaching digitally printed clothing production. The research provided some implications for apparel design and manufacturing, including the potential to facilitate adoption of mass customization by small business retailers/manufacturers as they strive to meet the need of consumers in rapidly changing retail environments.

11.5.2 Pioneering case studies in digital textile printing production

Rory Crichton and Giles Deacon

Rory Crichton has been leading innovations in digital textile design technology for many years, acting as collaborative textile designer with a number of high-profile fashion designers, including Giles Deacon. Giles' couture and ready-to-wear collections have included digitally printed fabrics, predominantly printed at the Centre for Advanced Textiles, for the past three years. The print designs generated by Rory have been used in garments that are now being digitally produced for short runs by Giles. Figure 11.4 shows an example of the type of engineered imagery that Crichton has created for Giles. Crichton believes that his design practice is not really changed greatly by employing digital textile printing technology, as he has always used the computer to generate his imagery, regardless of the printing process used in production, but he does acknowledge that DIJP effectively reduces the 'translation' of

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11.4 Chain imagery by Rory Crichton for engineered print garment by Giles Deacon, 2006.

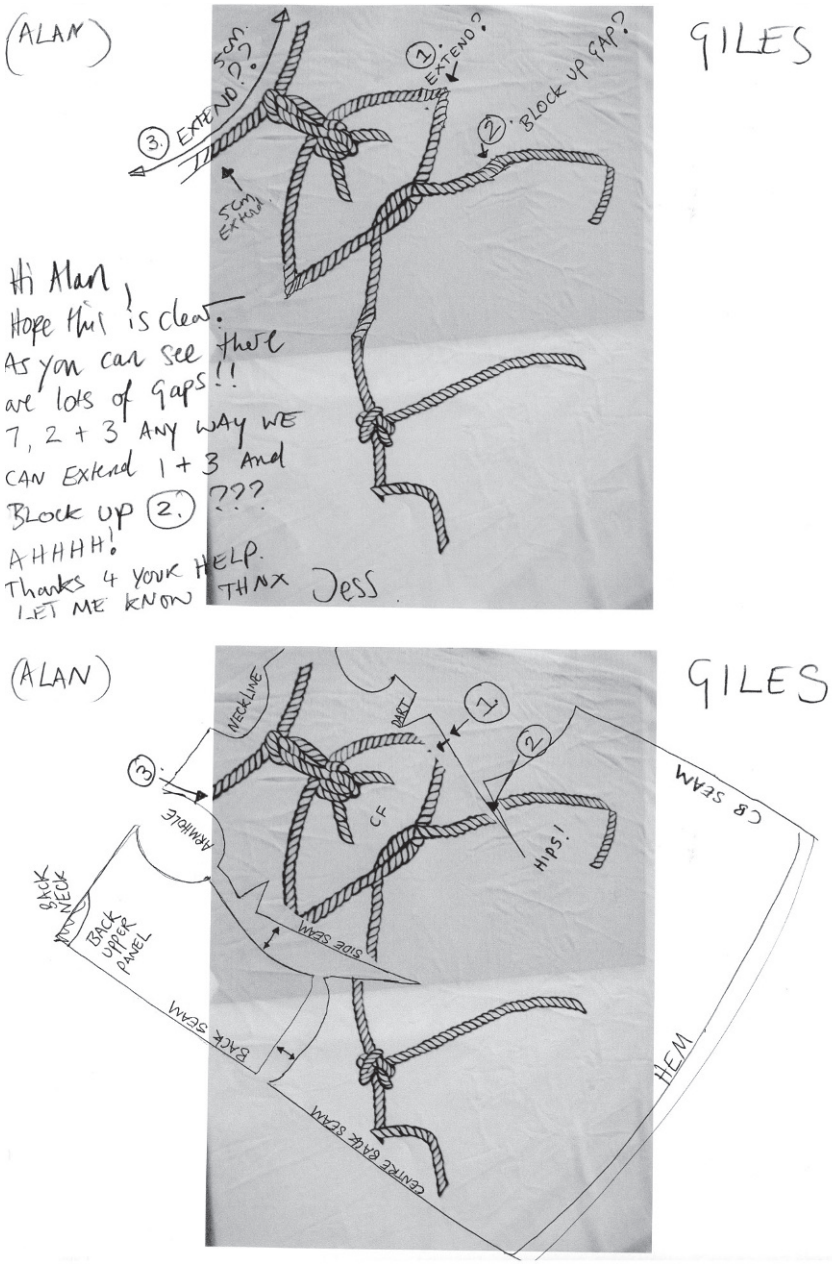
his imagery concepts as they are applied to cloth. In this sense, he thinks of DIJP output as being more 'true' to his design process. In collaborating with Giles, the patternmaking is done by hand, and so the imagery concepts that Rory creates, although placed within garment shapes, are not engineered directly into digital patternmaking files. As such, the production manager working for Giles communicates specific instructions to the digital printing service bureau about the placement and orientation of the images onto the length and width of the fabric. Figure 11.5 shows an example of working files that describe the garment shape and print placement to the digital print service bureau.

Pia Myrvold

Pia Myrvold is the founder of 'cybercouture.com', started in 1999 during fashion week in Paris with her 'clothes as publishing' concept called 'Dream Sequences'. Pia followed with the development of her cybercouture collections and an interactive online garment design studio concept dubbed the 'interactive studio'. An extract from a description of her 2003 collection follows:

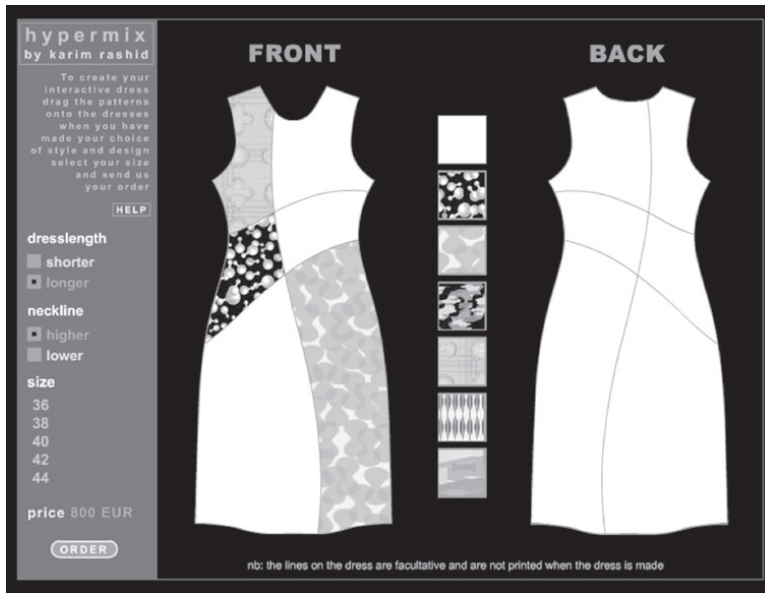
> Cybercouture Spring Summer 2003 is divided in three themes. Hypermix [shown in Fig. 11.6] and Cyberware are using innovative tools and technologies to produce highly complicated prints. Break-throughs in small-batch digital printing to fabric and innovative methods of customization permit cybercouture's couturiers to assemble unique garments. This allows for a collection of highly individual prints, draped on the body, like a sculpture or art piece, which can be produced on a per-order basis. It offers a completely new level of quality to consumers: one-of-a-kind couture at ready-to-wear prices [Examples of a completed garment from the Hypermix collection are shown in Fig. 11.7]. (Myrvold, 2003)

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11.5 Production printing communication notes for collaborative design by Giles Deacon and Rory Crichton. Instructions are for image correction and placement on fabric by staff at the Centre for Advanced Textiles digital textile printing service bureau.

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11.6 Online design interface of cybercouture by Pia Myrvold, Hypermix by Pia Myrvold and Karim Rashid.

The 'interactive studio' holds some of Myrvold's most innovative concepts for digitally printed production garments. In the site, one of the conceptual products (it is not functioning as an actual business yet) is the 'dubbeldam' customized garment. In this interface, a simple knit-dress template is shown over an animated video file to demonstrate how the imagery might fall into the garment shape. The goal is to capture an instant of the moving image, allowing customers to order that specific instance as an engineered print in the garment. A screenshot of the interface is shown in Fig. 11.8.

Myrvold describes her motivations for working with DIJP:

> The actual process of 'painting' each pattern piece with motifs is very exciting, it is much more like draping with colour, and it is hard to imagine now buying a print by the metre, when the distribution of the prints itself [creates] a new design experience. I used to do collections with forty garments… one digital dress design with an interactive interface takes about twenty times more effort in preproduction. But when the design is made, it stays forever. My vision with cybercouture, is a completely different game of production, distribution and customer service. It breaks all the rules of the fashion industry, but it creates a much higher design value for the customer, …[it] is an intelligent solution to problems of environment, overproduction, slave factories and other ethical concerns that I have had.

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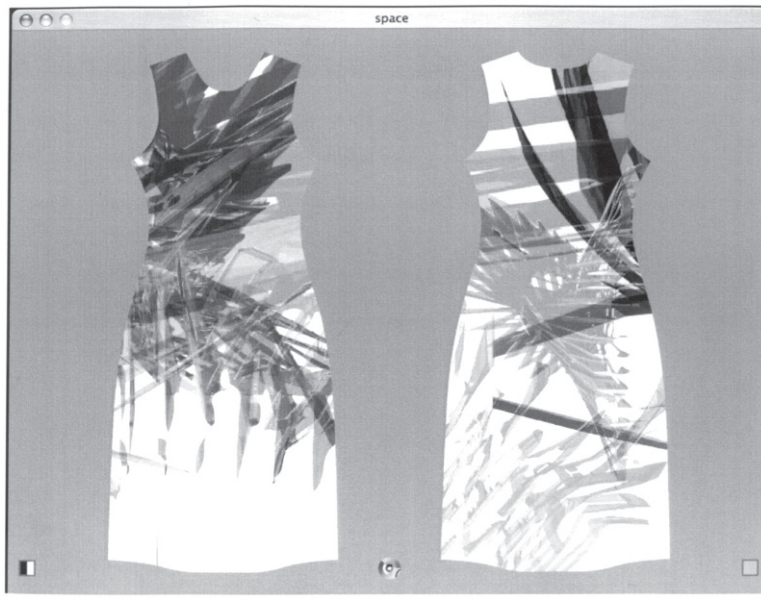


11.7 Hypermix dress configuration. Pia Myrvold and Karim Rashid. Photo model from presentation at Fellisimo Design House, New York, 2002 (Photo: Anne Senstad).

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11.8 Dubbeldam freeze online design interface. Pia Myrvold.

Other innovative examples

Designers Sue Firestone and Mimi Wolfe have translated R. W. Firestone's digital 'expressionist paintings and photography' (http://www.tamsen.biz/home.html) into vibrant all-over digitally printed fashion collections. In late 2005, Topshop created a new line segment termed 'Topshop Unique', which they introduced in runway presentations during London Fashion Week. The 'Unique' collection is produced in small quantities, and as a result they have chosen to use digital printing for both their prototyping and production. Mulberry has also begun using DIJP for prototyping and producing garments from their collections.

11.6 Future trends

It is no longer enough to be able to simply print fabric digitally; the industry is requiring colour matching and management throughout the design workflow, from drawing, scanning and digital photography; to calibrated monitors, creating output files using spectrophotometers; through to printing, finishing and garment assembly. Both technical developments and perceptions about the technology have evolved to a degree that applications for apparel production are truly possible.

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11.6.1 Increase in stratification of large production brands to address niche bridge to designer-level market segments

Continued developments in the applications of DIJP to clothing production will undoubtedly involve greater stratification within larger print production companies to allow for the use of digital printing to enhance their types of product offerings (as opposed to increasing their existing production quantities). Carlos Montero of Montero Seta SpA spoke to this effect in describing his company at the 'Creativity: Designer Meets Technology' conference in Copenhagen, 2005 (Montero, 2005). He demonstrated how his long-term customers who normally used the company for screen-printed fabrics have become more interested in supplementing their designs with unique, shorter-quantity printed fabrics that take advantage of the technology and depart from what can be created through screen printing.

11.6.2 Evolution of direct web-based production capabilities through social-networking-styled systems

The massive increase in social communities on the Internet (blog sites, YouTube, etc.) has forced the industry to realize that consumers desire to (in fact often feel they have the right to) respond and give feedback to designers and companies producing the products they buy. With increased fluidity between web-based interface software and back-end data management in communicating production information, the Internet provides ever-expanding opportunities to rethink the foundations of apparel production. The responsiveness of digital printing, when it is effectively tied into a web-based design and ordering interface, can bring the technology far beyond the era of rapid prototyping into a new era of reflexive production.

11.7 Sources of further information and advice

The Textile/Clothing Technology Corporation ($[TC]^2$), based in North Carolina in the United States continues to be a leading non-profit research and support company for advancing production strategies in the textile and apparel industries. They host a textile and apparel technology information forum on www.techexhange.com that is an endless source of useful information. Other resources include:

- The Center of Excellence of Digital Inkjet Printing of Textiles at Philadelphia University: currently led by Hitoshi Ujiie, the center has been engaged in a great deal of research on the technology and often

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holds workshops for people who are interested in learning more about the technology.
- The Information Management Institute: holds conferences on inkjet technologies, including focused events on digital textile printing.
- The Creative Institute for Design and Technology (KrIDT): based in Denmark, KrIDT is likely to become another world leader in digital textile printing research and teaching.
- Centexbel: Centexbel is the scientific and technological research centre of the Belgian textile industry and was founded in 1950 by the Belgian professional federation Febeltex (now Fedustria) to guarantee and reinforce the competitive force of the textile industry. Centexbel houses laboratories and research groups to investigate innovations in textile technologies (http://www.centexbel.be/eng/homepage.htm).

These groups and institutions represent a growing number of people who are actively involved in continued research, development, design and production in digital textile printing.

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12

Developments in pressing technology for garment finishing

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12.1 Introduction

In the high-volume clothing manufacturing industry, pressing is the final production stage and as such follows garment design, fabric cutting and making-up. The pressing process is used extensively throughout the clothing industry, both in garment production units and in the after-care processes of laundering and dry cleaning. The reasons for this are largely commercial, as pressing can be used to noticeably improve the appearance of clothing by removing unwanted creases and handling marks created during manufacture. Having thus restored a smooth outer surface to the item, this enhanced appearance makes the garment more attractive to prospective customers. The handle and the feel of clothing can also be improved by using a finishing process[1] to remove the glaze on a fabric by raising the nap of the constituent textile material; even though little pressure may be applied, such processes are still known as 'pressing',[2] which tends to be used as an all-encompassing term.

Pressing does not only apply to the process of crease removal and the enhancement of a fabric surface, it equally describes the insertion of specific creases into clothing, such as pleats in skirts, centre creases in trouser legs and the flattening of open side-seams. In addition to the creasing and smoothing operations performed on finished clothes, a fundamental use of pressing is in the development of a two-dimensional textile cloth into the three-dimensional form required of fabric components before and during the creation of a garment. In the formation of the complex curves needed to fit the human anatomy, pressing has long been used in conjunction with darts and shaped seams. Indeed, the most intensive use of pressing is during the multi-layer creation of hand-tailored, bespoke garments – particularly men's and women's coats and jackets.

The shaping of such garments around the chest, waist and shoulder is usually achieved using repeated application of small, simple, heated irons and tongs rather than utilising the large and sophisticated pressing equipment

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employed in mass production. Nonetheless, a limited amount of pre-pressing does feature during large-scale manufacture, as it aids the sub-assembly processing of cuffs, hems, lapels, waistbands and pockets; it simplifies the construction and improves the silhouette that may be obtained from the finished garment. It should be borne in mind that mass production primarily aims to generate affordable clothing of acceptable quality and the labour-intensive processes employed by high-class traditional tailors are not appropriate for high-volume manufacture.

The pressing processes that have been discussed are inherently aggressive in nature and are intended for use particularly with woven fabrics. By their very nature, knitted fabrics derive their properties substantially from the elasticity of their constituent yarns. It is therefore important to preserve their resilience during the pressing process. As a consequence, it is normal practice to use relatively low temperatures, minimal pressure and short exposure periods when working with knitted textile structures. Indeed, if excessive heat energy is applied to a knitted garment during the pressing process, it is likely that the fabric will become limp as the fibres lose their natural elasticity and the item will be rendered unsaleable.

12.2 The pressing process

The pressing process conventionally involves the application of heat, moisture (normally in the form of steam) and pressure, either individually or in combination.[3] A low-pressure facility is also commonly utilised to draw air through the pressed fabrics in order to effect rapid cooling. By such means, pressing is utilised to initially deform, then reform and finally to set textile fibres, yarns and fabrics in order to achieve a particular effect required by the designer.

The application of moderate heat to polymeric fibres results in changes to the fibre molecules. Raising the temperature of a synthetic fibre initiates an increase in the mobility of the polymer molecules and also causes dissociation of the hydrogen bonds and other inter-molecular forces, so that structural deformation can occur under the application of relatively low applied stress; the fibre is softened. On restoring the original, lower fibre temperature, the intermediate molecular bonds reform, thus supporting the modified structure which effectively stiffens in its new shape. This is termed a ‘temporary set’, as the fibrous material may be returned to its original form by simply re-heating and re-shaping it again.

If the temperature of a fibre is raised further, beyond its melting point, the fine structure of the polymer is irretrievably modified. This occurs as a result of the crystallites melting and flowing, so even when the fibre is cooled and it returns to its original temperature and stiffens, the textile material cannot be restored to its original structure. This is known as ‘permanent setting’,

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and is the process that forms the basis of melt-spinning. An interesting application of this technique may be seen in the manufacture of the fusible interlinings used for the stiffening of lapels in mass-produced jackets. The interlining is fabricated from bi-component fibres which incorporate a high melting point core polymer inside a lower melting point outer sheath. When the finished lapel (with the interlining inside) is heated, the facing and backing fabrics adhere to the melted outer layer of the interlining fibres, yet the structural integrity of the lapel is retained, because the inner core retains its shape. As it cools, the lapel structure sets into a single stiffened unit.

The equipment used to execute the pressing process is available in a wide variety of forms, from simple hot-metal hand-irons to large and complex computer-controlled machinery. However, the fundamental pressing procedure itself is conceptually straightforward. A typical sequence of operations for the pressing of an item of clothing may be as described below.

- Initially the garment is placed on a suitably shaped surface.
- Heat energy is applied, to plasticise the textile fibres in the fabric; steam is commonly employed for this purpose.
- While the heated fibres are pliant, pressure is applied to mould the fabric into the shape determined by the contact surface of the press.
- The fabric is dried to remove moisture from the condensed steam.
- Cooling is introduced to set the component fibres into their new shape; this is usually achieved by using a suction pump to draw cool air through the garment.
- Once the fibres in the pressed fabric have set, the garment may be removed from the press.

It should be emphasised that this is a simplistic overview of the pressing process; some aspects of the procedure are more critical than others and the various steps in the process will be examined in greater detail as different types of pressing process are described. Equally, not every pressing and finishing process utilises all the steps listed above, as differing types of pressing machine are designed to emphasise particular aspects of the pressing process in order to achieve the required result efficiently.

When pressing knitwear made from acrylic yarn, the garment is either mounted on a perforated mould or alternatively, the garment is placed on a flat, padded surface through which damp steam may be injected. If pressure is required in the operation at all, it must only be very gentle, to avoid distorting the fabric and this is applied manually by the operator using a hand-held smoothing pad.

12.3 Pressing with pressure

As there are a multitude of different designs of pressing equipment in use within the textile industry, each offering its own specific advantages over

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other types of equipment, it is proposed to consider mechanical pressing initially, as it conforms most nearly to the general pressing model described in the previous section. The oldest and most familiar approach to pressing will be considered initially, as it is conceptually very simple, yet offers a useful insight into the operation of more complex pressing machines before these are tackled in earnest.

12.3.1 The smoothing iron

The modern domestic steam iron developed from the original flat irons used for smoothing household laundry. Historically, these were usually made from flat iron plates with iron handles and a polished underside. In size and shape they were surprisingly similar to the electric iron in use today; having a point at the front, parallel sides and a square back. They were, however, much heavier as they were fabricated from a substantial piece of solid cast iron rather than being based on relatively thin aluminium, stainless steel or ceramic sole-plates as in current domestic equipment. Of course, flat irons were passive devices, without heating elements, and they were used in pairs; while one was in use, its twin would be placed on a hot plate so that it could absorb heat energy into the mass of iron of which it was made. Once the iron in use had lost too much of its heat energy and had become too cool, it would be exchanged for the hot one.

In its present stage of development, the domestic steam iron is a comparatively lightweight device (generally around 1.5 kg), incorporating a thermostatically controlled electric heating element, and having a water tank built in for the generation of steam. The temperature of the iron may be pre-set by the operator and similarly steam generation may also be selected if appropriate for the constituent fibres of the textile material being worked on. Many domestic irons are also capable of expressing a jet of steam if extra energy is needed to remove a sharp crease.

The industrial version of the hand-iron is usually part of an ironing station, as shown in Fig. 12.1, and offers the same facilities as the domestic one but commonly uses a floor-standing boiler to provide copious amounts of steam and this is fed into the iron through a high-pressure hose. The iron is often suspended from a cantilever arm using a counterbalance spring, to ease the drudgery of wielding the iron over extended periods of time, as illustrated in Fig. 12.2. This also allows the iron to be heavier when required; industrial irons generally weigh between 1.0 and 2.5 kg. Industrial steam irons may be fitted with a hard or soft brush to assist in crease removal, and they also have options for the fitting of Teflon or non-shine sole-plates. Irons are also available in a selection of shapes for specialised tasks; ranging from wide, heavy irons for removing and re-positioning creases and for pressing winter coats to small, narrow irons for flattening open seams on shirt sleeves.

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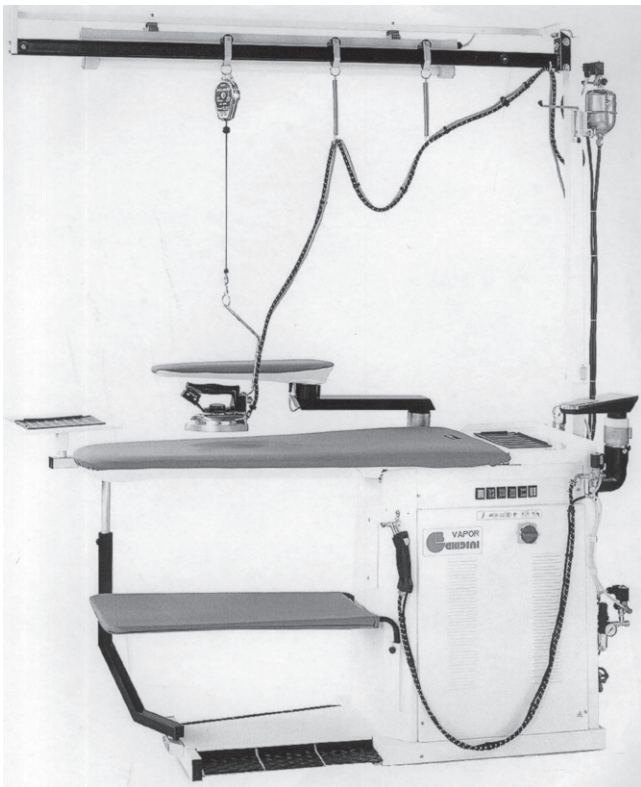


12.1 A basic industrial ironing station; the last stage of a making-up line. (Courtesy of Sun Flag Ltd, Arusha, Tanzania.)

It is the professional ironing station that differs most noticeably from the domestic equivalent. While a domestic ironing surface is little more than a flat, padded board, the industrial version offers in addition a range of hinged bucks of different thicknesses, curvatures and sizes, and these may be quickly swivelled into position in front of the operator to ease the task of ironing sleeves without creases and the compound curves on shoulders. The main ironing surface as well as the hinged bucks can be fitted with a vacuum facility; the suction is useful for holding clothing in position while it is pressed, and it also acts to remove heat from the work piece efficiently so that it may be removed quickly once the task has been completed.

Specialised workstations with a blowing function are employed for ironing coated fabrics that have, for example, been given a water-resistant finish and thus do not readily allow the passage of air or steam. By inflating such garments a raised surface is presented for ironing and this much reduces the likelihood of marking the surface with an impression of a thick taped seam. The blowing unit also facilitates the pressing of lightweight garments such as underskirts and unstructured night attire.

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12.2 Dress board ironing station with both air suction and blowing. The unit is shown with a swivel arm and sleeve buck; it also has a cantilever iron support gantry. (Courtesy of Ghidini Benvenuto SRL, Milan, Italy.)

The ironing process essentially follows the pressing sequence outlined in Section 12.2. The procedure commences by placing the garment or item of textile fabric on a flat, padded work surface that is capable of withstanding elevated temperatures.

- Initially, the fabric or garment is placed on a padded work surface.
- The vacuum facility may be used to help position the work piece.
- The iron is pre-heated up to its selected working temperature.
- The iron is applied directly to the upper textile surface of the item being pressed, so heat is transferred into the material by conduction.
- If it is being used, steam aids the transfer of heat by penetrating into the structure of the textile yarns.
- The heat transfer process plasticises the fibres of the textile fabric.
- The softened textile material is re-shaped by the pressure of the hot iron which presses it against the flat padding on the work surface.

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- The vacuum then aids the removal of moisture deposited by the condensing steam, and the air drawn through the garment speeds the cooling and setting of the textile fibres.
- The garment is then removed and left to dry to avoid the development of mildew.

12.3.2 The Hoffmann press

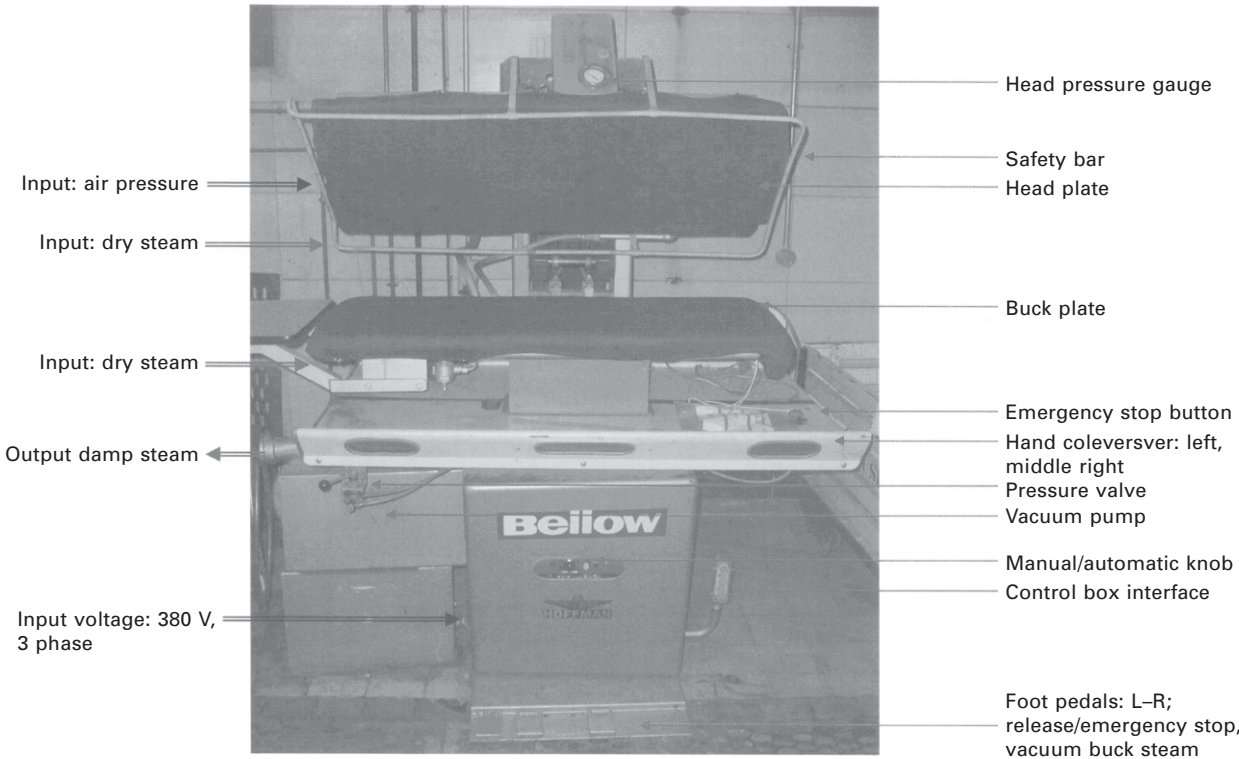
It might reasonably be argued that the Hoffmann press is the industrial incarnation of the domestic steam iron, as it is the workhorse of the high-volume clothing industry and it applies steam, heat and pressure during its operating cycle. This type of machine is categorised as a 'buck press' because it has a static buck upon which items are placed ready for pressing. The major components of the press are indicated in Fig. 12.3 and the various facilities may be operated under manual control or in a pre-determined sequence regulated by a programme control card.

The Hoffmann press is constructed with a static buck and a hinged head plate, these two major components are virtually identical in size and shape and close using a scissor action. During manufacture, garments to be flattened are positioned on the buck plate which incorporates a perforated silicone foam surface pad mounted on a protective felt sheet. This compliant cladding helps to distribute the steam evenly and also the pressure. The padding provides a soft surface which also limits steam damage to the fabric being pressed.[4] Garments must be smoothed by hand before pressing as they are inaccessible once pressing has commenced. The head plate features a padded surface similar to that of the buck; the two operating surfaces may be pre-heated. At the commencement of the pressing cycle, the head plate is driven downwards by a pneumatic ram and the head plate is locked onto the buck. The pressure developed between the two pressing plates may be regulated using a pressure valve, and is indicated on a gauge. Dry steam may then be injected into the press, through the perforated cladding; temperatures well in excess of 100 °C are easily attainable as a consequence of the operation being performed under considerable pressure. The steaming period must be carefully timed, as the steam may be very hot, and the total energy injected into a fabric has to be carefully controlled.[5] Steaming is immediately followed by the application of a gentle vacuum to help remove any damp steam, but mainly to draw cool ambient air through the pressing area and set the fibres in the garment so that it may be removed without damage to its shape once the pressure is released and the press opened.

The Hoffmann press is valuable in industrial clothing manufacture because it can process garments very quickly; it uses very hot dry steam, high pressure and swift cooling. In order to avoid damage to the textile fabric, it is very important to control the timing of each stage accurately. So, although the

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12.3 The Hoffmann steam press.

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press may be manually controlled using hand switches and foot pedals, it is possible to connect a programmable control facility using the control box as shown at the lower right-hand side of the schematic diagram in Fig. 12.4 and this allows each phase of the pressing cycle to be accurately started and stopped with reference to a real time scale.

The Hoffmann press is well suited to the insertion of creases into clothing and, by accurate measurement of the crease angle[5, 6] that can be introduced into wool fabrics, it was found that short pressing cycles at temperatures between 120 and 130 °C produced optimal results.[7] This emphasises the hostile nature of steam pressing, as wool fibres start to degrade at 125 °C. Pressure plates of different shapes and sizes may be used in conjunction with specific pressing cycles to perform highly repeatable pressing operations for a variety of garments and garment components.

12.4 Pressing without pressure

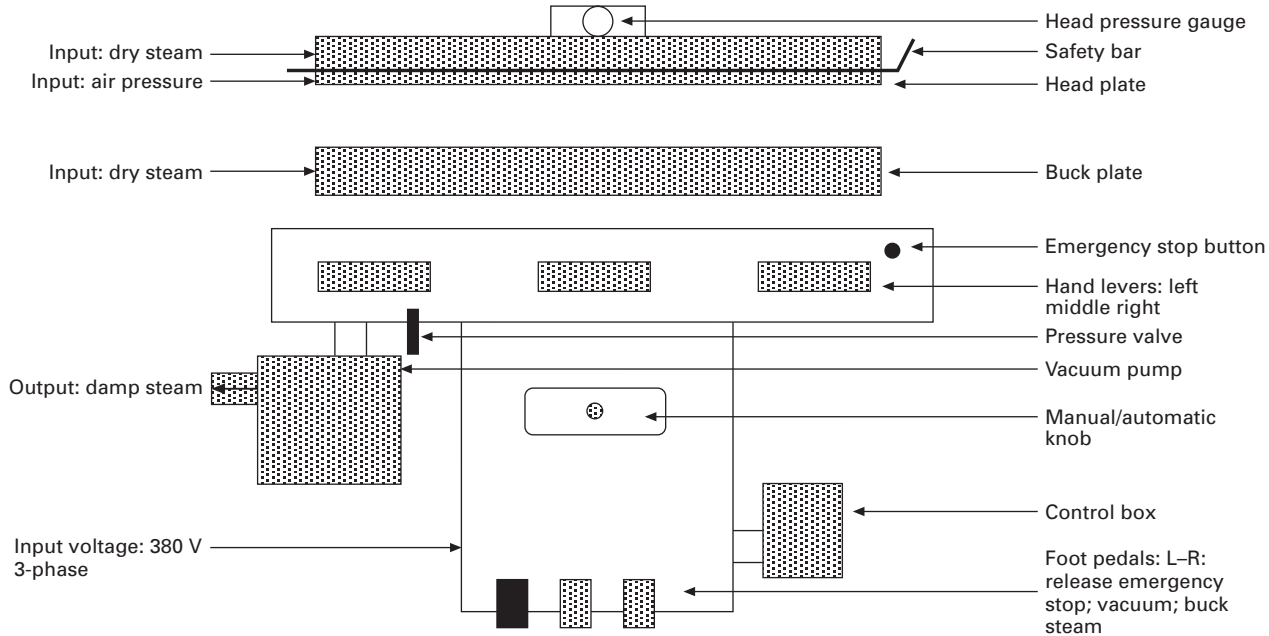
It is not uncommon in textile processing for the situation to arise where the removal of minor creasing is required, to improve the appearance of a garment or a fabric, but where the mechanical damage inflicted by the comparatively high temperatures and pressures that accompany conventional pressing are inappropriate. For example, re-finishing is commonly performed on consignments of garments that have suffered a long period of transportation following offshore manufacture. The re-finishing process may be carried out using a buck press, but without closing the head. However, finishing machines usually occupy this processing niche because they are capable of higher throughput and also because they provide a relatively gentle action to improve the appearance and the feel of textile materials.

12.4.1 The tunnel finisher

Steam finishing using a tunnel process is based around a continuous conveyer to which garments on hangers are attached. The conveyor first draws the garments through flexible entrance curtains into a steam cabinet. Once inside, the garments are exposed to low-pressure steam. The condition of the steam inside the cabinet is continuously monitored using temperature and humidity transducers and is modified under computer control. Hot air may be mixed with the steam to adjust the humidity; however, as the environment is unpressurised, it is not possible to provide steam in excess of 100 °C. Dry, superheated steam from a pressurised generating source inevitably suffers adiabatic cooling as it expands into a cabinet that is at atmospheric pressure. The damp steam that results relaxes the textile fibres, but offers only a limited capability to remove creasing, as the temperature is not particularly high and the only tension on the fabric is that due to gravity. After exposure

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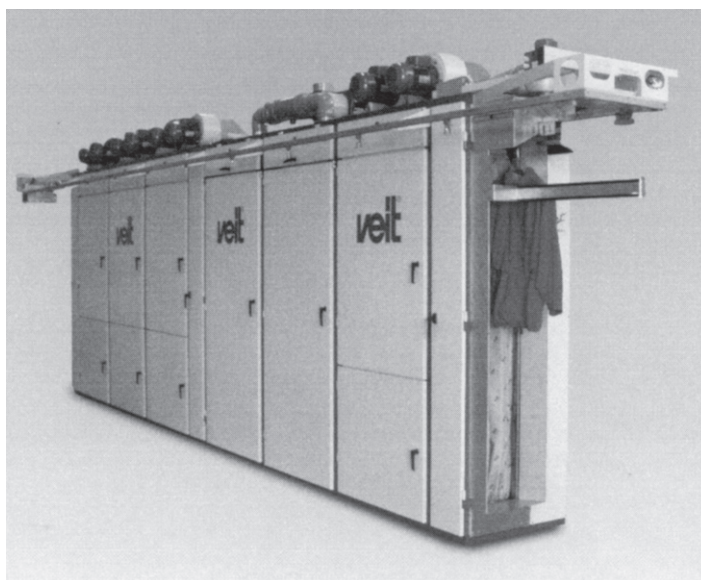
12.4 Schematic diagram of the Hoffmann steam press.

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to damp steam, the conveyor transports the garments into a drying area where warm air is blown through the garments, primarily to remove moisture and to inhibit the development of mildew. In order to improve the capacity for crease removal, turbulence is commonly introduced into the air flow to help shake out the creasing from woven fabrics. The high level of automation that is normal with tunnel finishers is extended to the running of the conveyor, the speed of which, together with the length of the tunnel, determines the exposure time of the garments to the steaming and drying processing stages. The tunnel finisher depicted in Fig. 12.5, manufactured by Veit GmbH, is capable of processing 3000 garments per hour using synchronised conveyor loading and it is optimised for energy efficiency. The dried garments often proceed directly to a bagging machine that wraps them in a clear plastic film, still on their hangers.

The strength of the tunnel finisher lies in the fact that garments do not have to be repositioned for particular operations on specifically shaped areas; the whole garment is pressed in one operation. Furthermore, items passed through a tunnel finisher are not subjected to mechanical compression at any stage, hence there is virtually no likelihood that they will suffer crushing of the nap or glazing of the surface, which produces a shiny area.[8] Indeed the steam finishing treatment tends to relax the constituent fibres and raise the nap, and provide improved (softer) handling characteristics and a matt finish to the textile fabric.



12.5 Tunnel finisher. (Courtesy of Veit GmbH, Landsberg/Lech, Germany.)

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Such treatment is well suited to knitted acrylic fabrics. However, the control programme is usually adjusted to reduce the steam temperature and dwell time so that energy absorption into the fabric is reduced. Furthermore, the garments are usually presented on frames, as their weight would tend to distort the shoulder area if they were to be suspended from a conventional clothes hanger. As crease removal is less of a requirement than with woven goods, there is little need for turbulence at the drying stage, and infra-red driers are often used.

12.4.2 The steam-air (dolly) finisher

Steam-air finishing is specifically intended for use with completed garments. This category of finishing equipment comprises either a metal dummy (mesh space-frame) shaped appropriately to support a knitted garment which is placed over this former in preparation for processing. Alternatively, for clothing made from woven fabric, a partly inflated porous cloth bag may be provided onto which a shirt or jacket may be placed ready for finishing (Fig. 12.6). Similarly, two long thin bags may be used for pressing casual trousers such as chinos or jeans, where creases are not required.

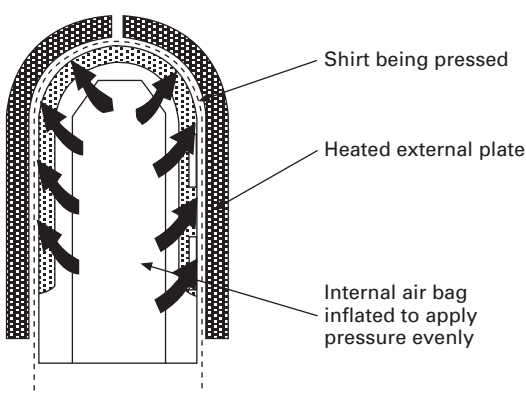


12.6 Blouse dolly finisher. (Courtesy of Veit Kannegiesser GmbH, Vlotho, Germany.)

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The operator commences a finishing operation by locating an item of knitwear on the former (or a woven item on the dolly bag) and with the clothing in position, the operator then initiates the finishing cycle. This commences with the injection of steam into the former. If a dolly bag is being used, the bag will inflate until its expanded size is constrained by the garment mounted on it. Steam continues to be injected into the cloth bag and percolates through this and into the garment being finished; sufficient steam is blown through the system to inflate the sleeves on shirts or jackets. Hot, damp steam carries energy throughout the material of which the garment is comprised, where it softens its constituent fibres. This plasticising effect, in conjunction with the tension created in the garment as a result of the inflation of the dolly bag, acts to remove minor wrinkles and superficial marks, and raises the nap of the fabric. The steaming cycle lasts for around 10 s, depending on the type of material being used and on the temperature and quality of the steam. At the end of this cycle, hot air is blown through the finisher in place of the steam, hence the garment is dried to preclude the occurrence of mildew. A third cycle, that of cold air ensures that the textile material has been set before being subjected to the stresses and strains of the removal process. The whole process extends over about 30 s.

It may be noted that clamps are usually applied to button bands to prevent distortion of the tensioned fabric around the buttons. For very delicate fabrics, a non-stretch woven cover may be placed over both the garment and the dolly bag to prevent excessive straining of the material as it is inflated, as may be seen in Fig. 12.7.



12.7 The Veit TwinStar shirt press utilises heated external shaping plates in conjunction with an internal air bag which inflates to apply even pressure to the garment. (Courtesy of Veit GmbH, Landsberg/Lech, Germany.)

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12.5 Crease-resistant finishes

Fabrics made from cotton fibres are easily creased during washing, wearing and handling due to the structure of the fibre. The chemistry behind the creasing of cotton derives from the bonds between the cellulose chains of which the natural fibres are composed. The cellulose cotton fibres are held together by hydrogen bonds and other weak inter-molecular forces. These are easily broken when the fibres are deformed, heated or exposed to water. The breaking and reforming of bonds is a reversible process, so that by placing a textile fabric in a desired form and by then subjecting it to heat and moisture, the fabric will assume the new profile, as the hydrogen bonds in the constituent fibres will dissociate due to the heat energy and moisture, and will subsequently reform and stabilise in the new shape. This is why a jet of hot steam is applied to remove stubborn creases in cotton.

Any cross-linking between the crystalline cellulose chains will restrict the movement of those molecules relative to one another, and this will limit the amount of creasing that can occur in a cotton fabric. A typical cross-linking agent that can be introduced to limit the dislocation of the cellulose chains is dimethyloldihydroxyethylene urea (DMDHEU) which has four reactive sites that interact with the cellulose molecules to form covalently bonded cross-links between the polymer chains. This crease-resistant finish is applied after dyeing and is then cured at 180 °C for about 2 min to initialise the reaction with the cotton fibres. It is, of course, possible to make up the whole of a garment from dyed fabric that has been treated with DMDHEU before initiating the curing process.

12.6 Permanent creasing

The creases that can be set into wool fabrics by steam pressing have limited durability when they are subjected to machine washing.[9] However, easy-care woollen garments with durable creases can be created by applying an ultra-violet curable, liquid resin finish. This involves applying a water-soluble mono- or multi-functional monomer or oligomer to the pre-formed crease. Subsequent exposure to photons of high-energy ultra-violet light initiates conversion of the applied chemical into a cross-linked polymeric network. Applications of polyester triacrylate have been shown to out-perform polyurethane diacrylate treatments.[6]

12.7 Future trends

The use of pressing in clothing manufacture was originally intended primarily for modifying the shape of textile components from their two-dimensional manufactured form into a three-dimensional contoured profile that would

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better fit the anatomy of the customer. Small heated irons are still used for precisely this purpose in the creation of high-quality bespoke tailored garments. Even in the mass-production environment, clothing is still subjected to hand-ironing or is placed in pressing machines by hand. This is because the operator needs to smooth the fabric surfaces and remove wrinkles before the pressing cycle is initiated, so that unwanted creases are not pressed into the cloth.

The smart presentation of outerwear is a societal expectation and regular ironing is still a widespread, time-consuming and unpopular domestic activity. As a consequence, there has long been considerable incentive to automate the ironing process and work in this area still continues, but with little commercial success. The very act of driving a metal bar across a compliant textile fabric tends to distort the material and create wrinkles which are subsequently pressed into the surface. Rotating brushes may be introduced to smooth the fabric surface before pressing, but increasing levels of complication and expense are undesirable. Robotic ironing systems using images fed from cameras might ultimately prove practical, but introducing such technology into the domestic environment appears some way off. This task has long proven to be intractable and it increasingly appears that the solution will derive only from continued developmental effort.

One area where improvements are being successfully introduced into pressing and finishing is in the increasingly effective use of computer control. Sophisticated transducers are being progressively introduced to monitor the physical properties of the pressing medium; the gathered information is subsequently analysed by the controlling computer and used to ensure that an appropriate amount of energy is transferred during the pressing or finishing process by regulating the temperature and humidity of the steam, and by determining the exposure time of the clothing being processed. Different fibre mixtures have specific optimal pressing requirements. By controlling a process more accurately, the results become ever more repeatable.

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13

Automated fabric inspection

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13.1 Introduction

In this chapter, the focus is on fabric inspection and analysis with particular emphasis on garment manufacturing in the fashion and apparel sector. There is also a discussion on a technique that has been developed to analyse the test results from the Kawabata Evaluation System (KES) and generate automated written reports that give an indication of fabric sewability. A simplified methodology for producing a fingerprint of the fabric has also been developed. Computer software has been created that automatically analyses the results from Kawabata hand tests and, using this information, successfully generates an automated textural report of the fabric properties. It also produces guidance as to the sewability of the material.

13.2 The principles of textile inspection

Textiles and clothing have been synonymous with human activity for thousands of years and as the years have progressed their usage has become wider and more varied. The types of clothes worn, for example, have become more diverse as new fabrics have been developed. Generations of fashion gurus have emerged anxious to exploit the market with new and innovative creations.

In the modern textile mill, fabric or cloth is commonly tufted, woven or knitted in pre-determined widths on high-speed, automated looms and knitting machines. It is common on these machines for the threads supplying the machines to break, thus causing expensive stoppage times. These stoppages are often the result of imperfections in the yarn such as slubs, yarn irregularities and impurities of one kind or another. It is important that flaws within the material, that have arisen during processing, are detected as soon as possible so that the problem can be corrected and production recommence.

As individuals have become more fashion conscious, attention to quality has become more of an important issue. The consumer is always seeking

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better value for money. As the consumer has become more discerning regarding the choice of their clothing, manufacturers have had to accept that attention to quality is a major issue, which could ultimately affect their own survival. Therefore, companies are examining all aspects of the manufacturing process, more so now than at any other time in the history of modern manufacturing.

One of the most common causes of poor-quality finish to garments is seam pucker, which may be defined as wrinkles or creases and folds in the fabric.[1] This phenomenon is not solely attributable to the machine processing of the material. There are many other factors that contribute to poorly finished garments, not all of which are associated with the making-up process. Fabric for example has very many physical and chemical properties associated with it as it can be produced in many ways using extremely varied fibre and yarn twist types. Recent developments such as micro-fibre fabrics, fabrics with laminated coatings, different finishes and treatments of materials all contribute to and modify the make up performance of the material. There are many other factors involved that produce problems during making up. Some of these have been defined as:

- seam slippage;
- seam damage;
- seam grinning;
- seam cracking;
- seam pucker.[2]

There are other contributing characteristics also, and out of a wide range of parameters it is difficult to identify which influences the behaviour of the fabric when sewn and why one consumer chooses a garment made from one fabric rather than another. This makes it extremely difficult to discover which properties and manufacturing processes contribute to the problems exhibited.

Such complexities have been perplexing clothing manufacturers for years and probably will continue to do so due to the seemingly endless amount of variability associated with textile materials. It is therefore of great importance to the clothing industry to identify what can be done to minimise disruptive problems and what procedures can be put in place to improve the situation.

Where fashion and aesthetics are concerned, one of the crucial aspects of manufacturing apparel is how the garment looks and handles when it has been made. Experts within the clothing industry have traditionally evaluated the handle of fabrics by means of a subjective hand approach. This has usually consisted of certain physical movements such as touching, rubbing, bending, stretching and pulling. This subjective method is still very commonly used in industry today. However, the development of scientific methodologies has meant that these fabric parameters can be tested and quantified into

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scientific data, allowing a more accurate picture to be established in terms of 'finger-printing' the fabric.

There are many areas, however, that have yet to be addressed. The first centres on the measuring of fabrics after they have been manufactured. The problem facing apparel manufacturers is that once the fabric has been made, there is limited value in telling the manufacturer that the fabric is going to present a problem when sewn. Preventative measures on the factory floor are not enough in themselves to eliminate problems in the making-up process, so consequently such problems will continue to arise during manufacture.

The second consideration is in the testing of the fabrics after manufacture in order to predict their sewing performance and stability. The Kawabata system for example has become synonymous with the mechanical testing of fabrics using a series of tests that have been developed and are now used by companies and scientific institutions around the world. The resultant data from these tests produce a fabric 'fingerprint' that provides technologists with information about how fabrics will perform when being made up into garments. A technologist interprets these fabric fingerprints and a report is usually produced for the company that has commissioned the test. This report is usually prepared manually and involves a subjective analysis of the objective test results. Preparing such reports takes considerable time. The fingerprint produced can also be difficult to interpret by untrained staff. The people who view these reports, usually production management and technical staff, need to be able to interpret the results quickly and efficiently so that effective measures can be implemented on the factory floor to prevent trouble if the fabric is deemed to be problematic. Therefore, a means of automatically interpreting the results from the Kawabata system and a simpler way of creating the fingerprint has been developed as part of this research work.

The system is designed to simplify the procedure by which the results can be input and a report and a 'fabric fingerprint' generated in a fraction of the time it takes to produce a manual report. The system is intended to be factual and accurate and has been tested accordingly by feeding in a variety of suitable test data and analysing the results. This tool can also be designed to operate on a number of different types of equipment to analyse the data from any objective measurement system, for example the KES or Fabric Assurance by Simple Testing (FAST).

In addition, a comparative analysis has been carried out of the present Kawabata 'fabric fingerprint' system and the new Fabric Sewability System. This has been achieved by using an approach similar to that devised by Kawabata with the co-operation of the Hand Evaluation and Standardisation Committee (HESC) of the Textile Machinery Society of Japan (TMSJ).[3]

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13.2.1 Containing the sewing parameters – discussion

When sewing fabrics together, there are a number of factors that need to be taken into account:

- machine settings;
- needle type;
- type of sewing thread used;
- operator handling;
- fabric parameters.

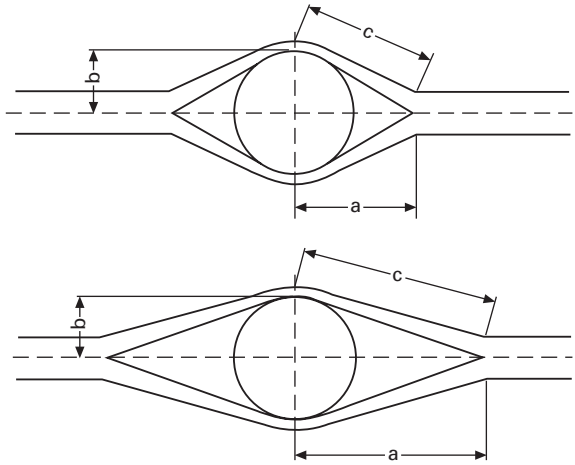
All of these areas are important in producing a quality seam. If one or more of them are incorrect, a poorly sewn and finished garment can result. Therefore, well-organised companies have assessment structures in place in order to minimise production downtime. Garment technologists, quality managers and clothing machine engineers have a contributing role in minimising or eliminating production problems,[4,5,6] but in order to eliminate the problem, an understanding of the problem has first to be achieved.

Fine woven fabrics, for example, are particularly susceptible to seam pucker caused by structural jamming of the sewing thread within the yarns of the fabric. If the fabric is densely woven near to the practical weaving limit, there may be insufficient spaces to accommodate the sewing thread without distorting the woven yarns. The problem is aggravated if hard twisted yarns or extra fabric finish are used. Stitching along a straight line will distort and stretch the adjacent fabric yarn or yarns. The distress caused to the yarns may produce a puckered seam.

A seam running parallel to the warp direction often tends to pucker more than a seam running parallel to the weft direction. This is because the warp yarns are subjected to higher tension during the weaving process. The result is a higher compression strain between the yarns in the fabric and the sewing thread in the seam in the warp direction compared with less compression between yarns and sewing thread in the weft direction. A slight change in the design or cutting of the fabric so as to enable the critical seams to be sewn at a 10° bias angle will often reduce this problem. This is because the sewing thread runs at an angle to the warp or weft direction so that the compression strain between the yarns in the fabric and the sewing thread in the seam is distributed more widely and is therefore significantly reduced (Fig. 13.1).

Sewing machine settings should normally be set as dictated in the machine manual, and gauges and a magnifying glass should be used to ensure that the machine is set up perfectly. There are, however, circumstances when the sewing machine may be set up differently from the manual; i.e. when sewing different thicknesses of seam or for difficult sewing operations, such as sewing collars and cuffs on shirts, for which the feeder may need to be tilted

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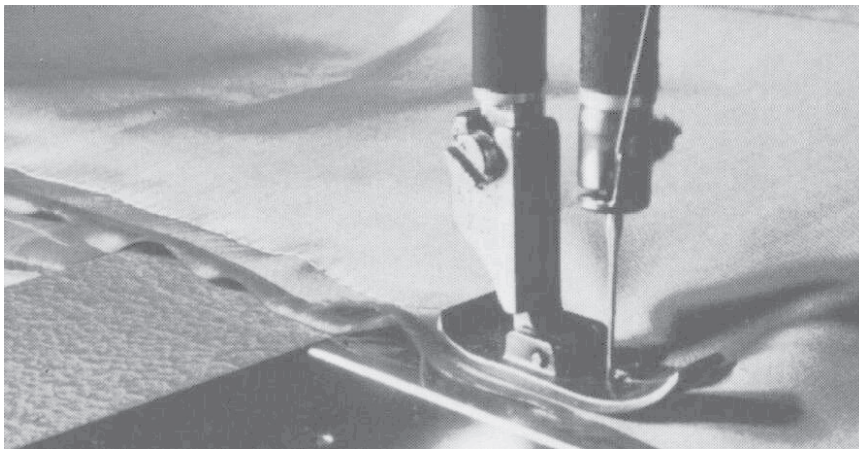
13.1 Structural jamming of the sewing thread between the yarns in the fabric.[7]

to the front to enable the machine to catch the first stitch. As a rule, the industrial standard for setting thread tensions is to have both top and bottom thread tensions as slack as possible while producing a well-balanced stitch. Similarly, the presser foot pressure should be set as low as possible. However, if the pressure is too low, there is a loss of control of the fabric and the top and bottom fabric layers may not move together through the sewing stage. If the pressure is set too high, it can cause the machine foot to push the top ply of the fabric, thus displacing it from the bottom ply causing 'feed pucker'. Establishing the correct values for these fundamental settings is known as 'machine optimisation'.

Other factors that should be addressed include ensuring that the correct type of feeder and throat plate are used for the fabric. A throat plate with a hole that is too large for the needle causes flagging of the fabric. This is a condition whereby the fabric is pushed into an oversized needle hole by the descending needle. This causes a number of problems, which can include missing stitches because the sewing thread loop is malformed inside the machine causing the rotary hook to miss the thread loop. An example of fabric feed pucker is shown in Fig. 13.2.

Operator handling is a factor that frequently changes for many varied reasons. Fabric parameters differ from batch to batch, even with regard to the same style and type of product. Fabrics tested on the Kawabata system can have widely varying results, even from the same batch of fabric. Therefore, in order to implement procedures to prevent a problem that has been highlighted by the Kawabata system, a thorough understanding of the sewing process and the fabric assembly method needs to be achieved.

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13.2 Example of feed pucker.

13.3 The Kawabata Evaluation System

Since the beginning of scientific research into textiles, one aim has been to devise measurements that could be used to predict the behaviour of textile fabrics. Much of the earlier work can be attributed to Peirce in his paper 'The handle of cloth as a measurable quantity' published in 1930.[8] In this paper, he establishes equations that define such phenomena as the bending length of the material. Basic machines are developed that measure and calculate the flexural rigidity of the fabric. Tests are described that have been designed to analyse and reflect the sensations of stiffness and hardness of the fabric and numeric values are awarded accordingly. The judgment of Peirce in 1930 was that:

> The quality of the finish of a cotton fabric is a matter that concerns its appeal to the judgement of the buyer on the evidence of his senses. The judgement depends on time and place, on seasons, fashions, and personal and racial predilections, so that it would be futile to replace expert or aesthetic appreciation by the numerical results of a physical test. The evidence of the senses, on the other hand depends on the physical properties of the material, so that physical measurements can be of great value in providing data on which to exercise judgement… those aspects of 'hand', that can be included under the generic name of 'stiffness' can now be reinforced by simple physical measurements.

His measures of stiffness relate to:

- bending length;
- flexural rigidity;
- thickness;

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- hardness or resistance to compression;
- bending modulus;
- compression modulus.

Other pioneering work followed. Research, carried out at the Swedish Institute for Textile Research (TEFO)[9] in the late 1950s and 1960s, involved the evaluation of low stress mechanical properties such as bending, buckling, stress, shear and compression in respect of tailorability and the investigation of deformation of the fabrics into garments.

Lindberg and others have applied the theory of buckling to textile fabrics in garment technology. Research established the fact that longitudinal fabric compression is a fabric mechanical property that is particularly important during tailoring. Lindberg related this property to fabric formability. Tatsuki Matsuo, in the Toyobo research centre, Japan,[12] developed test methods and identified parameters that built up a significant collection of fabric samples, which provides an 'atlas' of fabric hand, combining subjective feel and objective characterisation.

Much of the modern work now used for objective measurement in universities and industry is attributed to Professor Sueo Kawabata of Kyoto University and his associates, with the support of the TMSJ. Kawabata and Niwa[13] discussed both the subjective and objective methods of fabric hand and concluded that the benefits of objective measurement over subjective measurement are:

- that objectively evaluated values are not influenced by the individual opinions/preferences of judges;
- fabric hand may be clearly connected with fabric mechanical properties;
- fabric hand data may be recorded by numerical value as well as mechanical measurements on the database. This is important for the development of new fabrics, for process control in textile manufacturing, for marketing and for sales-related stock control of textiles.

The people who buy the fabrics, the consumers and even the fabric processors have a considerable expertise when choosing what type of fabric to wear or buy. The pioneering work by Kawabata has brought about a new approach to this problem with the development of four pieces of equipment and the identification of 18 parameter values that are derived from the test results. The hysteresis behaviour of the fabric, the bending movement and the compression force are measured in order to determine the fabric resilience and other mechanical properties. The mechanical properties of the fabric are essential in enabling the objective fingerprint to be produced. The mechanical parameters of the KES are shown in Table 13.1.

Kawabata's work with the HESC in 1972 is well documented.[15–21] A subcommittee of 17 experts from the TMSJ were invited to join the Committee. These represent predominantly the industries of wool, fabric, weaving and

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Table 13.1 Mechanical measurements used in the Kawabata Evaluation System[14]

Parameter	Description
Tensile	
LT	Linearity of extension curve
WT	Tensile energy
RT	Tensile resilience
EMT	Extension at 500 gf/cm load
Bending	
B	Bending stiffness
2HB	Bending hysteresis
Shearing	
G	Shear stiffness
2HG	Shear hysteresis (0.5°) movement
2HG5	Shear hysteresis (5°) movement
Surface	
MIU	Coefficient of friction
MMD	Mean deviation of MIU
SMD	Geometrical roughness
Compression	
LC	Linearity of compression curve
WC	compression energy
RC	compression resilience
To	Thickness at 0.5 gf/cm^2 pressure
Tm	Thickness at 50 gf/cm^2 pressure
Weight	
W	Weight per unit area

finishing, and the silk industry. The Committee identified the primary hand factors for textile fabrics and these were initially used in the composition of a subjective assessment. The factors were described as follows.

1. Men's winter suiting fabric
   - *Koshi – stiffness*. Stiffness deriving from the bending property. High-density fabrics made from springy and elastic yarn usually possess this feeling strongly.
   - *Numeri – smoothness*. A mixed feeling incorporating smoothness and softness; coming from a smooth, limber and soft feeling. The fabric woven from cashmere has this feeling.
   - *Fukurami – fullness and softness*. A feeling associated with bulky, rich and well-formed fabrics ('fukurami' means 'swelling').
2. Men's summer suiting fabric
   - *Koshi – stiffness*. Same as koshi in men's winter suiting fabric.
   - *Shari – crispness*. A feeling coming from a crisp and rough surface of the fabric. This feeling is brought by hard and highly twisted yarn. This offers a cool feeling. (This word means a crisp, dry and sharp sound arising from rubbing the fabric surface against itself.)

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- *Hari – anti-drape stiffness*. Anti-drape stiffness regardless of whether the fabric is springy or not. (This word means 'spread')
- *Fukurami – fullness and softness*. Same as fukurami in men's winter suiting fabric.

From these primary hand factors, Kawabata produces calculations from which he derives the total hand factor of the fabric. This fabric fingerprint is graphed using a line chart. An example of the data chart developed by Kawabata is given in Fig. 13.3 (see also Fig. 13.4).

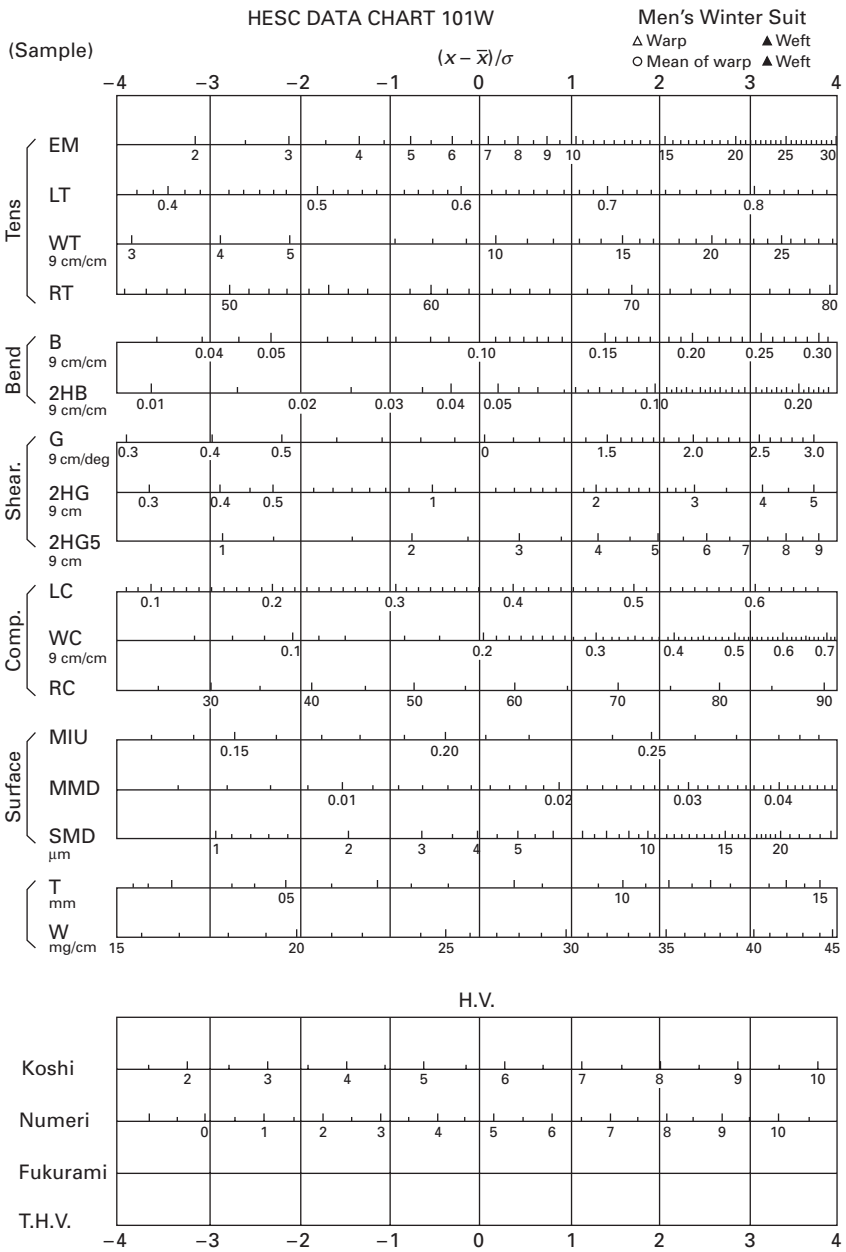
There have been many interpretations of Kawabata's work. It has been suggested in a number of papers (for example, Hearle and Amirbayat[22]) that Kawabata uses too many measurements and that fabric predictability, particularly with respect to manufacturing, may be quantified using fewer test measurements than was previously thought. Hearle and Amirbayat explore this by suggesting the use of short cuts to the Kawabata method. This involved a smaller relevant list of parameters and fewer test instruments based, not on new experimental work, but on an examination of data available from Kawabata's existing publications. They deduce that the factors responsible for the listed properties are the fabric structure (type of weave and geometrical parameters), the yarn properties and the finishing properties. They conclude that the parameters used by Kawabata may be simplified by taking into account the inherent relationships between many of the quantities as influenced by the fabric. Interestingly, they also conclude that in the absence of KES instruments, a limited number of parameters can be measured with ordinary laboratory equipment; i.e. the thickness gauge, the balance and the bending length tester can be used to estimate the total hand value of a wide range of men's winter suiting fabric with a good degree of accuracy.

Much has been made of the use of KES instruments in predicting the processability of fabrics in sewing. Harwood *et al.*[23] discuss uses for the Kawabata system in producing consistency in fabrics for the clothing-manufacturing sector. They mention the fact that dyers and finishers are not fully aware of the ways in which their choice of processing route or processing conditions can affect a fabric's mechanical properties. By using the KES or similar equipment, the way in which mechanical properties vary with the methods used in processing are easily quantified.

There are, however, schools of thought that suggest that a pitfall is developing, in that some apparel manufactures and finishers, due to advanced publicity, have viewed the KES as a panacea that is deemed to be the answer to all the hand and variation problems. This does not seem to be a realistic viewpoint as some ground work needs to be done to categorise and understand the measurements.

As to the ultimate use of the KES as a universal standard for evaluation of fabric hand, at the Philadelphia College of Textiles and Science conference

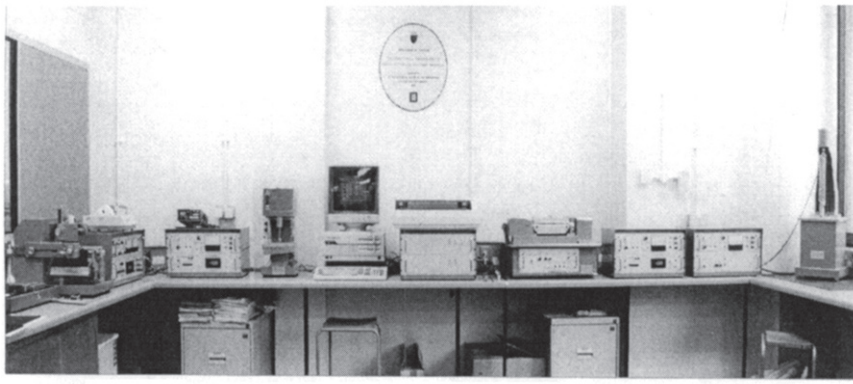
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13.3 Example of the HESC data chart.

on 'Objective Specification of Fabric Quality' held on July 19th 1983, the discussion was centred around the use of KES-F as a design and development tool rather than a routine quality control device. The true benefits of using

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KES testers in the Centre for Objective Measurement of the Department of Textiles at UMIST, Manchester, England

13.4 Kawabata Evaluation System (KES).

the system would become apparent as more units were used in the United States for evaluation. It was also concluded that a developed objective measurement system for hand and finished characteristics would be of considerable value to the textile industry.

13.4 Fabric Assurance by Simple Testing

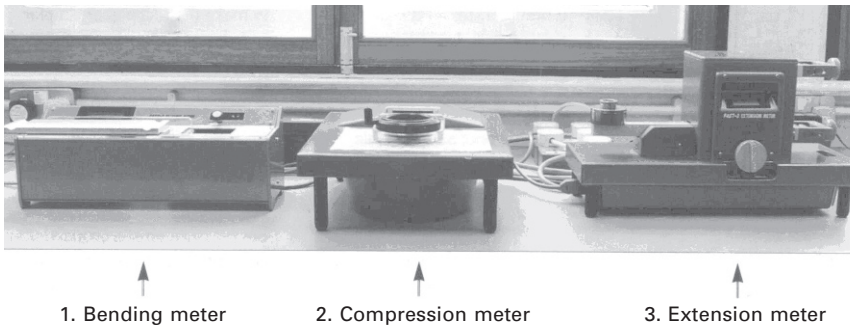
The FAST system was principally designed for use in the tailoring and worsted finishing industries.[24] The major advantage of this system is its cost and simplicity of use. The emphasis of the system has been that it should be user friendly and robust enabling fast and accurate measurements to be taken (Fig. 13.5). FAST works by measuring and interpreting the parameters that have been identified by scientists at the Commonwealth Scientific Division Research Organisation (CSIRO) as being critical to fabric appearance, hand and performance during the garment-making operation. It comprises three instruments and one test method. These are classified as:

- FAST-1 compression meter;
- FAST-2 bending meter;
- FAST-3 extension meter;
- FAST-4 dimensional stability test.

The equipment takes the following measurements:

- tensile properties;
- extension at three loads;

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13.5 Fabric Assurance by Simple Testing (FAST).

- fabric thickness;
- bending length;
- relaxation shrinkage;
- hygral expansion.

Test results can be obtained within 1 h and most importantly the equipment is easier to operate than the Kawabata system. It is stated that it takes less than 1 h to train unskilled staff to operate the system.[25] The only other additional requirement is that the fabric be conditioned before being tested.

- The FAST-1 compression meter measures the fabric thickness at various loads and measures the surface layer thickness.
- The FAST-2 bending meter measures the fabric bending length according to BS 3556-1961. The bending length is converted into bending rigidity, which is directly related to fabric stiffness. Operator error in aligning the sample is eliminated due to an optical sensor mounted on the machine.
- The FAST-3 extension meter measures the fabric extension at various loads. The extension is displayed as a percentage with a 0.1% resolution. The bias extension is also measured, and is converted to shear rigidity, which is directly related to fabric looseness. Fabric extensibility is combined with fabric rigidity to give fabric formability which is a parameter related to the incidence of 'seam pucker'.
- The FAST-4 dimensional stability test is not an instrument but a test method used to calculate the dimensional stability of the fabric. The test requires a laboratory oven and the fabric is subjected to a cycle of drying, wetting and then drying again. After each stage, the fabric's dimensions in both the warp and weft are measured. The FAST system claims to give valuable information to the garment maker as to how the dimensions of a fabric will change when exposed to moisture. The test method enables the dimensional stability of the fabric to be split down into two clearly identifiable components, whose cause and effect are quite different. These two components are relaxation shrinkage and hygral

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expansion. Relaxation shrinkage is defined as the irreversible change in fabric dimensions (shrinkage or expansion) that occurs when a fabric is wet or exposed to steam. Hygral expansion is the reversible change in the dimensions of the fabric that occurs when the moisture content of the fibres is altered.

Another advantage of the FAST system is that it can be linked directly to an IBM-compatible PC via the FAST data acquisition and analysis program. This program enables the test results to be recorded and fabric 'fingerprints' to be printed automatically on a standard computer. Both the KES and FAST systems have been analysed and compared in previous papers.[25–27] Correlations between the KES and FAST systems have been made and show striking similarities between both types of system.

Since its introduction to the industry in 1989, it is claimed that the use of fabric objective measurement has grown rapidly to the point where industry and commerce on opposite sides of the world can communicate in a common language. Case studies have been produced[28] that emphasise how the FAST system can be deployed to help companies by telling them how a fabric will perform before production. The fabric fingerprints can be used for fabric specifications, helping in developing new fabrics, comparing fabric finishes and predicting tailoring performance and final garment appearance. These case studies are representative of situations commonly found in industry.

From the use of the Kawabata system discussed above, its advantages in the sewing manufacturing sector have also been discussed in many research publications.[29–35] Newly developed fabrics can be tested before release into the market. Preventative procedures can then be implemented at the design stage to ensure that the fabric has properties that will enable its manufacture into garments without too many problems.

13.5 Automating the results of objective reporting and analysis (the Kawabata Evaluation System)

Two versions of the system were developed; one was a standalone program with its own built-in database system while the other uses Microsoft Access as its means of storing data. The inbuilt database system meant that each company record could be kept separately and accessed by clicking on its icon. The reason for developing both systems was to determine which system would prove to be better for managing the data. It was decided that the inbuilt database system would be used as each record could be contained separately for each company. Therefore, for the purposes of this research, it is this program that is explained.

The program focuses on the factors of the fabric that are particularly relevant to seam pucker and overfeeding difficulties. Therefore, it was necessary

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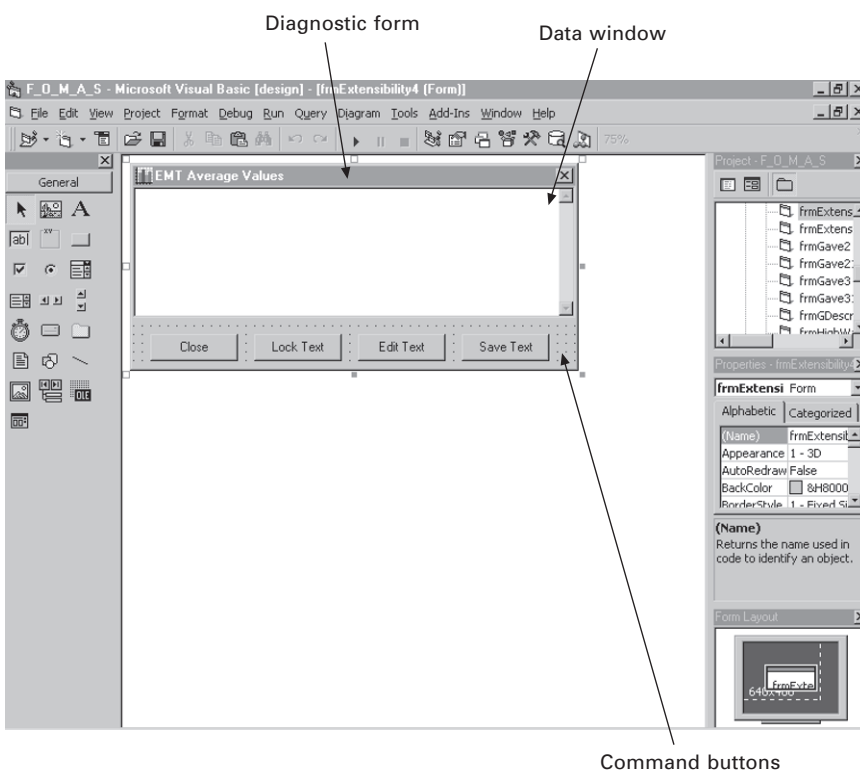
to identify the parameters from the Kawabata calculations that were responsible for these phenomenon. The following parameters were determined as the most important properties of sewing fabrics for fabric sewability.[36]

- extensibility (EMT);
- shear forces of yarns at work in fabric (G, 2HG, 2HG5);
- bending stiffness – flexural rigidity forces within the fabric (B);
- alpha (α) difference between two matching parts, warp and weft.

The average values of EMT, G, 2HG, 2HG5 and B from the Kawabata test data were used for the purposes of validation of the system.

13.6 Development of the main analysis form

The forms were made up of the following controls and objects: text boxes; command buttons; labels; picture box; common dialogue control. An example of the main form for the Fabric Sewability System is given in Fig. 13.6. The software is a distributable software product that can be loaded on to any PC running a Windows platform.



13.6 Diagnostic form, for the Fabric Sewability System.

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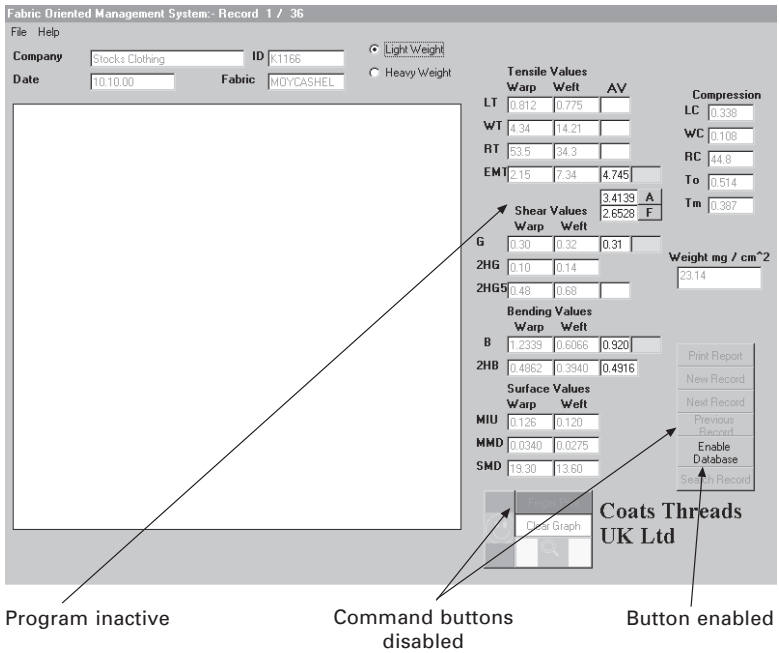
13.6.1 Description of the diagnostic forms

The diagnostic forms are produced when the 'Average Value' text box is activated by clicking on it. An example of a diagnostic form is given in Fig. 13.6. The text can be edited in the data window if the explanation needs to be modified. Enclosed within the system is a file in a separate folder called 'Kawabata Test Data'. This folder can be loaded into the documents folder. In this folder a file has been created called 'Bodyware Clothing'. This is a test data file that can be opened in the Kawabata program. Another file that comes with the system is a folder called 'KAWDATAFILES'. This folder contains the data files from the diagnostic forms produced when the values are activated. The contents of this folder are copied into the same folder as the program itself, which is 'C:\Program files\FSS'. Once the program has been activated and the password has been verified, the main form appears on the desktop.

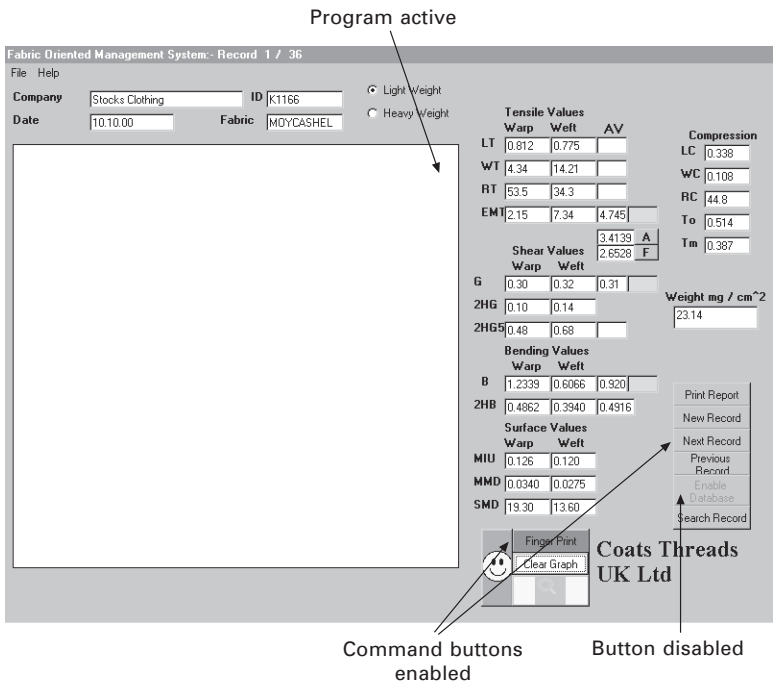
It can be seen that the initial window of the program is non-functional due to the command buttons and window-interface being disabled. Clicking on '**File**' at the top of the menu bar and selecting '**New Database**' will activate the program where a new database file can be created. This will enable records to be input for the company that has commissioned the test. The next step involves opening an existing database in order to add records to it. Selecting '**Open**' in the file menu opens the common dialogue box and the relevant file is located. Double clicking on it will open the database to access the company record (Fig. 13.7). At this stage, the text boxes and all command buttons are disabled apart from the '**Enable Database**' button. When this button is clicked, the program becomes active and the '**Enable Database**' button becomes inactive (Fig. 13.8). Data records can now be input by clicking on the command button '**New Record**'. The '**Next**' button and '**Previous**' buttons enable the user to move backwards and forwards through the records. The '**Search**' button searches for records by the 'K' (Kawabata Identification Tag) and will locate any record in the record set. The text boxes also contain the name of the company, date, fabric description and all the Kawabata data values obtained from the test. In addition to this, other values are automatically calculated when the '**Finger Print**' or '**Print Report**' buttons are pressed; these are the alpha value (warp to weft extensibility), the fabric formability and the value beta (ratio between warp bending stiffness and weft bending stiffness).

The fabric fingerprint is produced by clicking on the '**Finger Print**' button on the main form (Fig. 13.9). The laddered areas indicate the potential problem areas and are marked with the high and low values accordingly. These areas are derived from those used in the current fingerprint.[14] The spaces between the ladders are the safe areas. If the fabric values are within these spaces, it can be deduced that the fabric will present few problems during or after sewing.

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13.7 Access to the company record with form inactive.

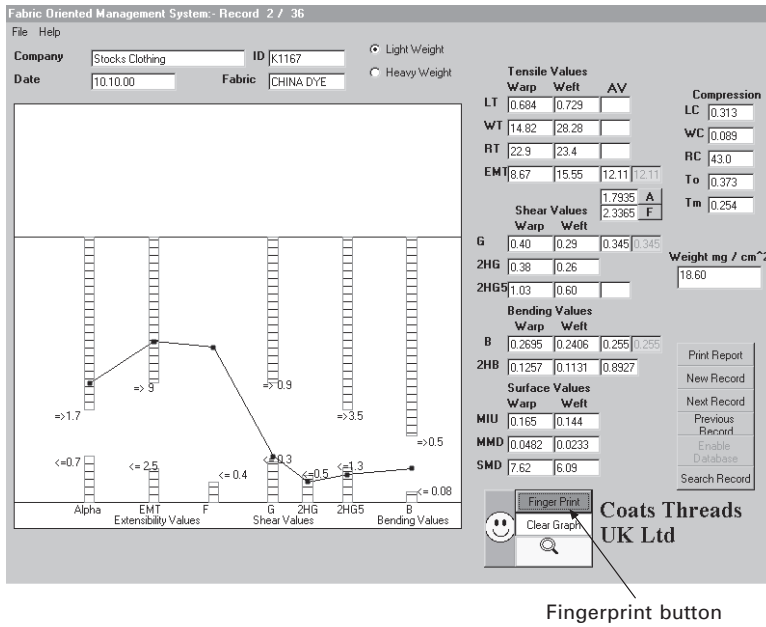


13.8 Company record activated.

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13.9 Fabric fingerprint generated by the system.

13.6.2 Report generation

The report is generated in two ways. In the first method, the report is generated by clicking on the '**Print Report**' button where a message box is generated that asks the user if they want to generate the report. If '**Yes**' is clicked on, the report is generated in Microsoft Word (Fig. 13.10). In the second method, the report is generated by clicking on the text box that contains the value that the user wants to examine. The program analyses the average values of the tensile measurements (LT, WT, RT, EMT), the shear values (G, 2HG5), the bending stiffness (B) and the alpha value (A). When any of these text box average values are clicked on, a diagnostic form window appears and an explanation of that parameter is given (Fig. 13.11). The contents of the diagnostic window can be copied and pasted into any word processing software. This gives the user more control over what is done with the text. Another advantage of this system is that the text can be edited and saved, enabling explanations to be updated.

13.6.3 Multiple fingerprint generation

The software allows the user to superimpose one fingerprint over another. This is useful when a company sends more than one fabric at a time and also when two fabric fingerprints need to be compared with one another. When

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COATS LTD

CUSTOMER: Stocks Clothing
FABRIC : MOYCASHEL
END USE :
DATE : 10.10.00
CONTACT :
OUR REF : K1166

Operation	Stitch type	Stitch rating per 3 cm	Stitch type	Point style	Needle thread	Under thread

Comments
Very low extensibility (e.g. less than 2.5% can cause overfeeding difficulty in warp and weft directions during making up. This value indicates that the fabric may be prone to over feeding difficulties. Seam pucker could also occur due to the fact that the insertion of the sewing thread causes a compression strain too high for the fabric to contain without pucker.
Shear properties measure the inter-yarn friction and indicate the ease of fabric movement. If the values are low, i.e. less than 0.3, then although it indicates that this is good for drape, comfort and handle, difficulties may occur in laying, cutting and making up due to the ease of fabric distortion. Sewing of long seams and pattern matching can be particularly difficult. Seam puckering may also occur as the extensibility in the bias direction is high.
Bending properties are mainly affected by the inter-fibre and inter-yarn forces in a fabric. This value is relatively high for bending stiffness and may affect fabric handle and drapeability and can result in needle damage.

13.10 Reporting system generated in Microsoft Word.

the 'Superimpose' button is clicked upon, another fingerprint is generated on the same form. The superimposed fingerprint is highlighted with a lighter shaded line (Fig. 13.12).

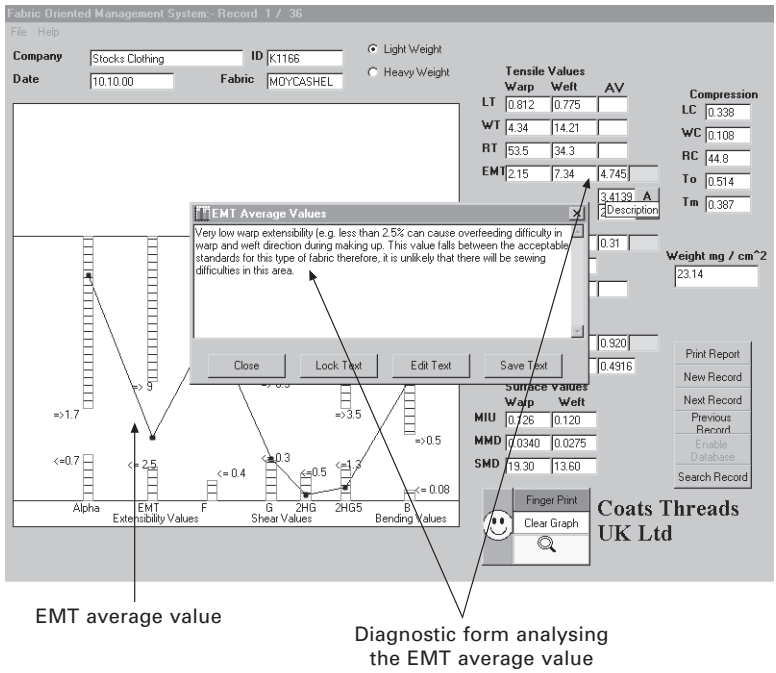
13.6.4 Fingerprint zoom control

The software has a fingerprint zoom facility that allows the fingerprint to be expanded into a full-size graph. This can be accessed by clicking on the '**Zoom**' button (Fig. 13.13), and by selecting the zoom facility from the file menu or by pressing '**F1**' on the computer keyboard. The fingerprint is then expanded to a full-sized screen (Fig. 13.14).

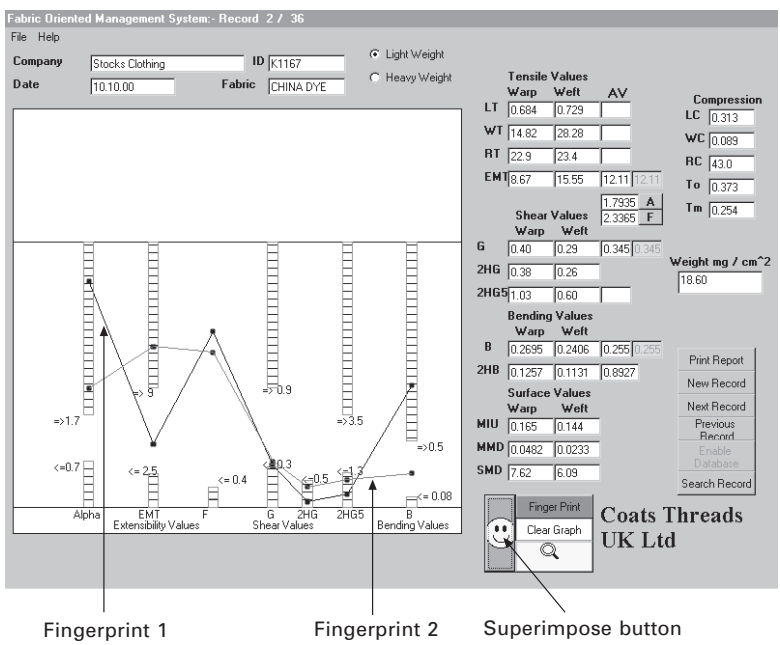
13.6.5 Algorithm development

Several techniques were used in the development of the analytical algorithms, so for each algorithm used in the program, an explanation is given.

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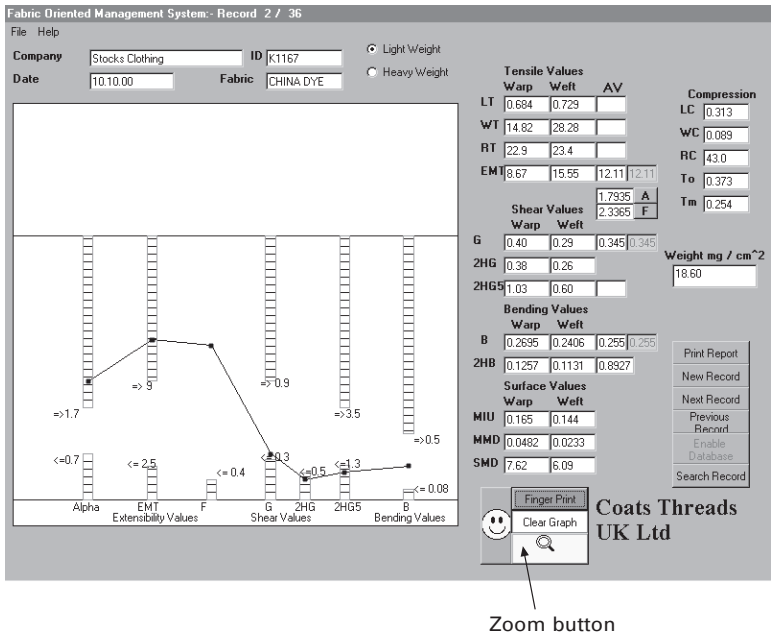
13.11 Parameter analysis can be obtained by clicking on the value.



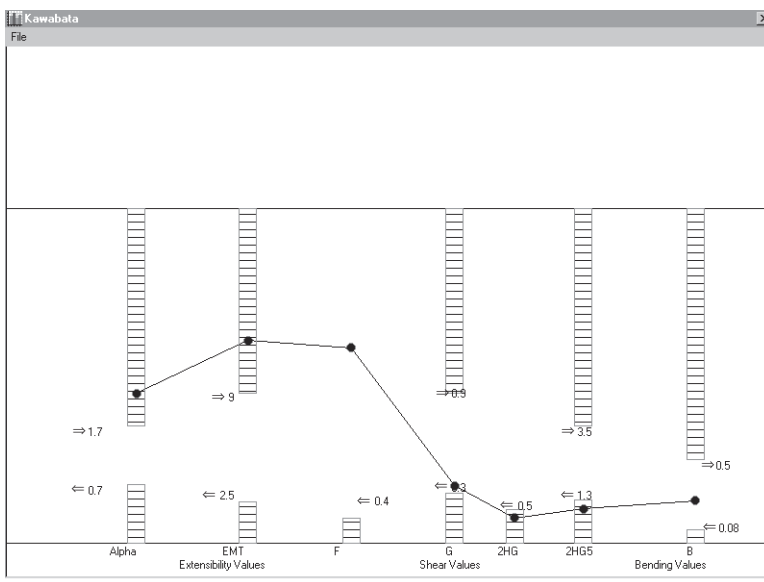
13.12 Generation of more than one fingerprint.

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13.13 Clicking on the '**Zoom**' button enables a larger image to be produced.



13.14 Larger fingerprint image.

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13.6.6 Trial algorithm

The first development of the algorithms was done using pseudo-code, which is an abbreviated version of computer code. This technique was used first to focus on the steps required to solve the problem before developing it in the computer language. The first example is given in Fig. 13.15. Using Fig. 13.15 as a model, the program was developed in a similar way to writing in a computer language but without being restricted by the rules of Visual Basic. The initial steps in the program were:

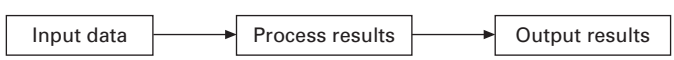
- Kawabata – create automatic report generation from the test results;
- enter the data in some form of text box – (Input);
- Analyse the data – (Processing);
- Print the data in a report – (Output).

From this initial work, the overall program structure was developed using a hierarchy chart that depicts the organisational structure of the program (Fig. 13.16). The algorithms have been solved by providing a series of instructions to each module that performs the calculations and displays the results in diagnostic and report format. The modular functions of the separate algorithms are described in the following sections.

13.6.7 Database algorithm

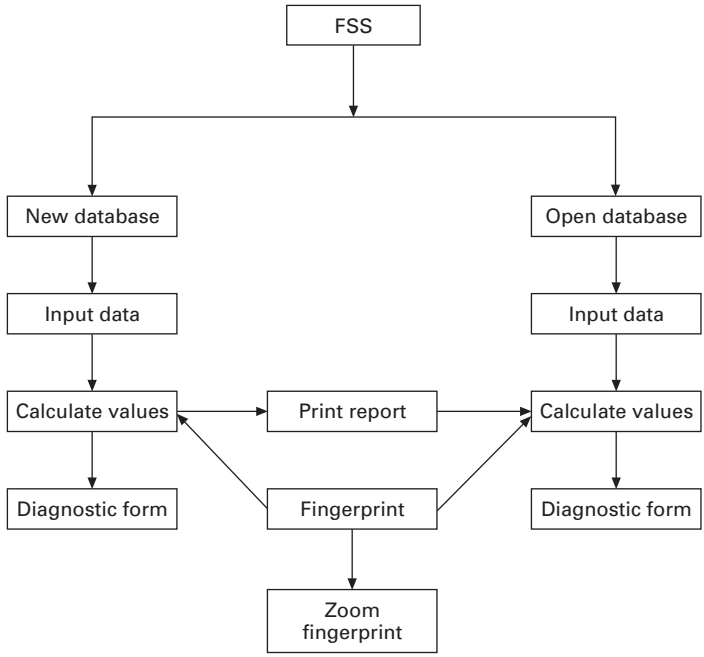
This is a standalone database system that allows the user to create separate records for each company. A flow chart of the algorithm can be seen in Fig. 13.17. This algorithm has been created with a number of logical steps of progression. First, a module is produced in Visual Basic where all the type variables are declared and string parameters are given. A string represents a set of printable characters, which means that each individual text box has a string length, which can represent either letters or numbers. The module declares the user-defined types of all the objects under one module name. An example of the module coding is given below.

```
Type TestData
'All the names below reside in the type test data as the user-defined type
CompanyName As String * 50
Date As String * 20
ID As String * 20
Fabric As String * 20
```



13.15 Trial algorithm.

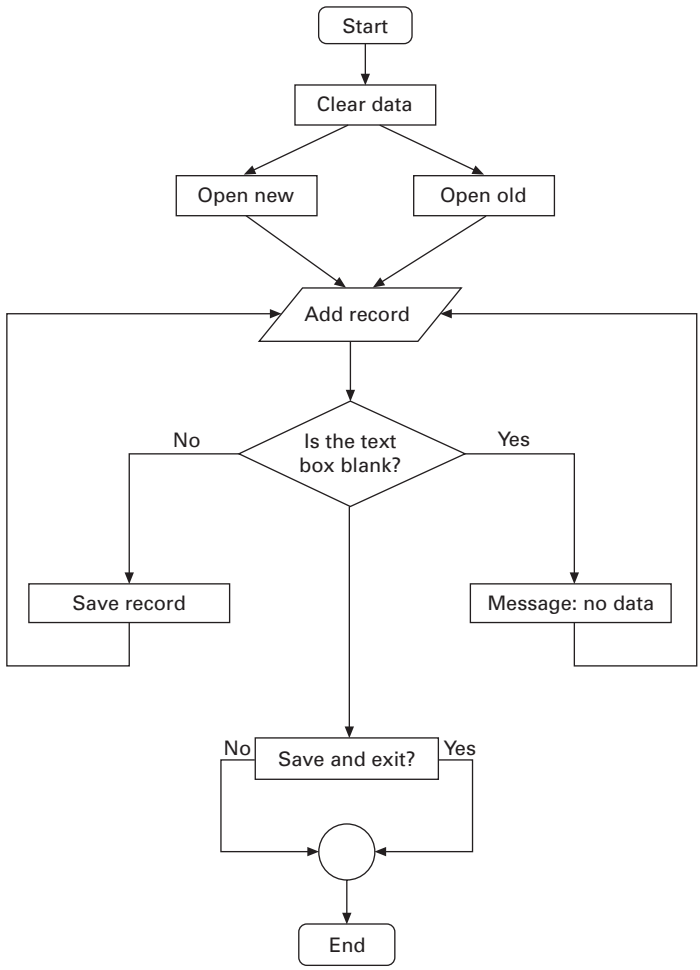
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13.16 Hierarchy chart illustrating the construction of the Fabric Sewability System (FSS).

```
WARPLT As String * 20
WEFTLT As String * 20
WARPWT As String * 20
WEFTWT As String * 20
WARPRT As String * 20
WEFTRT As String * 20
WARPEMT As String * 20
WEFTEMT As String * 20
WARPG As String * 20
WEFTG As String * 20
WARPHG As String * 20
WEFTHG As String * 20
WARPHG5 As String * 20
WEFTHG5 As String * 20
WARPB As String * 20
WEFTB As String * 20
WARPB2 As String * 20
WEFTB2 As String * 20
WARPMIU As String * 20
WEFTMIU As String * 20
```

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13.17 Database algorithm.

WARPMMD As String * 20
WEFTMMD As String * 20
WARPSMD As String * 20
WEFTSMD As String * 20
LC As String * 20
WC As String * 20
rc As String * 20
To As String * 20
Tm As String * 20
Weight As String * 20
EMTAve As String * 20
Beta As String * 20

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```
formability As String * 20
Alpha As String * 20
GAve As String * 20
bAve As String * 20

End Type
```

When the main form of the program has loaded, the program checks to see if there are any data still left within the form, if there is then the data are cleared ready for a new record to be input. This can be seen from the following coding example:

```
Private Sub Form_Load()
'Disable the command buttons
cmdNew.Enabled = False
cmdSearch.Enabled = False
cmdNext.Enabled = False
cmdPrevious.Enabled = False
cmdEnable.Enabled = False
cmdAnalysis.Enabled = False
cmdLineGraph.Enabled = False
Command2.Enabled = False
cmdClear.Enabled = False
Command1.Enabled = False

'When the main form loads all the text boxes should be blank if not then
make them so

txtCompanyName.Text = ""
TXTID.Text = ""
txtDate.Text = ""
txtFabric.Text = ""
txtWarpLT.Text = ""
txtWeftLT.Text = ""
txtWarpRT.Text = ""
txtWeftRT.Text = ""
txtWarpWT.Text = ""
txtWeftWT.Text = ""
txtWarpEMT.Text = ""
txtWeftEMT.Text = ""
txtWarpG.Text = ""
txtWeftG.Text = ""
txtWarp2HG.Text = ""
txtWarp2HG5.Text = ""

End Sub
```

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The general declarations of the program are the global variables that are used throughout during the program execution. The general declarations are always given at the beginning of the code. The general declarations for this example are given below:

```
'All the variables MUST be declared
Option Explicit
Dim gKawabata As TestData
Dim gFileNum As Integer
Dim gcurrentrecord As Long
Dim grecordlen As Long
Dim glastRecord As Long

Private Declare Function sndPlaySound Lib "winmm.dll" _
Alias "sndPlaySoundA" (ByVal lpszSoundName As String, _
ByVal uFlags As Long) As Long

'Constants for the sndPlaySound function
Const SND_ASYNC = &H1
Const SND_LOOP = &H8
Const SND_MEMORY = &H4
Const SND_NODEFAULT = &H2
Const SND_NOSTOP = &H10
Const SND_SYNC = &H0
```

The first five variables are the global variables used in the program. The gKawabata variable is dimensioned to the TestData as the declared type. The TestData is made up of all the names for the text box objects. The other four variables are dimensioned as numerical variables. The range of the variables is given in Table 13.2.

The '**New Database**' part of the program accesses the common dialogue control and opens the common dialogue box. The user types in a name and presses the '**Save**' button. The program is then activated and awaits records to be entered (Fig. 13.18). The '**Open Database**' dialogue box behaves in a similar manner to the '**New Database**' function but the program responds in a different manner. When the user wants to end the program, a message box is produced with the three buttons '**Yes**', '**No**' and '**Cancel**'. Pressing '**Yes**' saves the record, '**No**' exits the record without saving and returns the user to the program.

13.6.8 Fingerprint algorithm

The fingerprint algorithm consists of a mathematical expression that has been developed to enable the graphing of the data. It allows the results to be graphed at the click of a button. The fingerprint graphs the parameter values

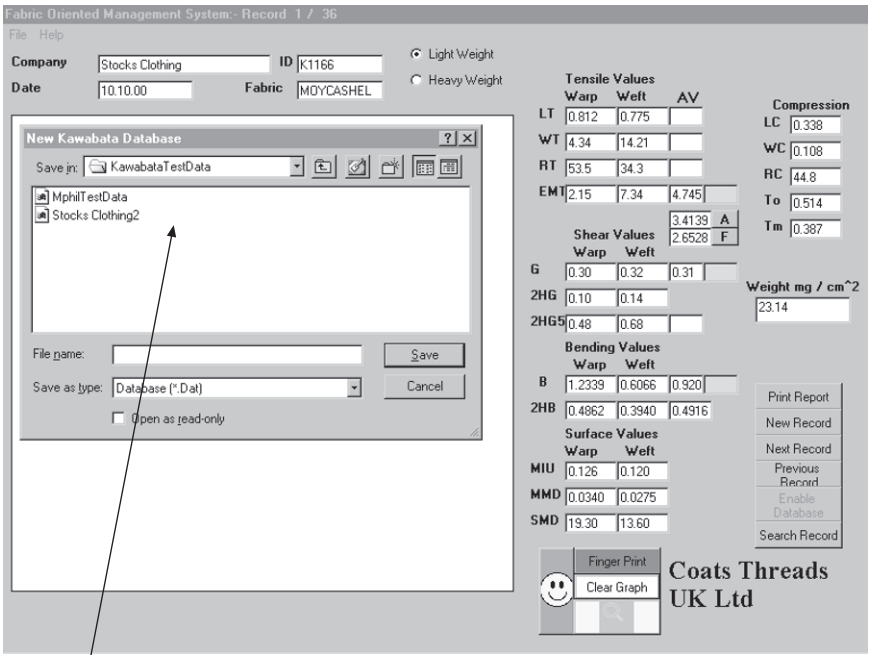
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Table 13.2 Numerical variables used in the program

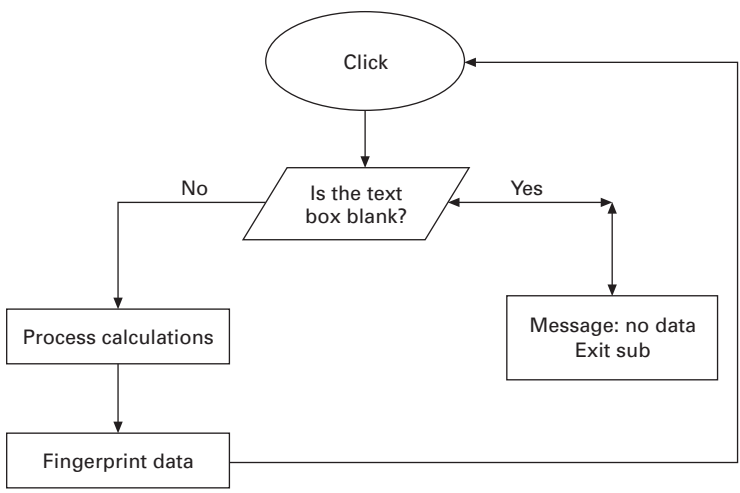
Data type	Storage size	Range
Byte	1 byte	0 to 255
Boolean	2 byte	True or False
Integer	2 byte	–32 768 to 32 767
Long (long integer)	4 byte	–2 147 483 648 to 2 147 483 647
Single (single-precision floating-point)	4 byte	$-3.402\,823 \times 10^{38}$ to $-1.401\,298 \times 10^{-45}$ for negative values; $1.401\,298 \times 10^{-45}$ to $3.402\,823 \times 10^{38}$ for positive values
Double (double-precision floating-point)	8 byte	$-1.797\,693\,134\,862\,32 \times 10^{308}$ to $-4.940\,656\,458\,412\,47 \times 10^{-324}$ for negative values; $4.940\,656\,458\,412\,47 \times 10^{-324}$ to $1.797\,693\,134\,862\,32 \times 10^{308}$ for positive values
Currency (scaled integer)	8 byte	–922 337 203 685 477.5808 to 922 337 203 685 477.5807
Decimal	14 byte	± 79 228 162 514 264 337 593 543 950 335 with no decimal point; ± 7.922 816 251 426 433 759 354 395 0335 with 28 places to the right of the decimal; smallest non-zero number is ±0.000 000 000 000 000 000 000 000 0001
Date	8 byte	January 1, 100 to December 31, 9999
Object	4 byte	Any 'Object' reference
String (variable length)	10 byte + string length	0 to approximately 2 billion
String (fixed length)	Length of string	1 to approximately 65 400
Variant (with numbers)	16 byte	Any numeric value up to the range of a 'Double'
Variant (with characters)	22 byte + string length	Same range as for variable-length 'String'
User-defined (using 'Type')	Number required by elements	The range of each element is the same as the range of its data type.

for EMT (average value), G (average value), 2HG (average value), 2HG5 (average value) and F (formability value). The alpha value and B (the bending stiffness value) are also graphed. The flow diagram for the fingerprint algorithm is given in Fig. 13.19.

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13.18 Common dialogue box for record selection.



13.19 Fingerprint algorithm.

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The code first looks at whether there are any data in the text boxes and if there is not, a message is returned saying 'no data'. If there are data in the boxes the fingerprint is graphed in the picture box control. The coding structure and mathematical expression are given below:

```
Private Sub cmdLineGraph_Click()
'If Text box is empty then return a message
If txtWarpEMT.Text = ""Then
MsgBox "No data for graph", vbExclamation

Exit Sub
End If

'Calculate the average value of the text boxes below
txtEMTave.Text = (txtWeftEMT.Text * 0.5) + (txtWarpEMT.Text * 0.5)
txtGAve.Text = (txtWarpG.Text * 0.5) + (txtWeftG.Text * 0.5)
txtBAve.Text = (txtWarpB.Text * 0.5) + (txtWeftB.Text * 0.5)

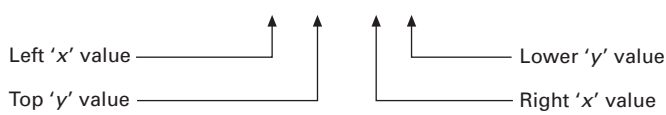
Calculate the various values of:
'Formability
txtFormability.Text = txtWarpEMT.Text * txtWarpB.Text

'Alpha
txtAlpha.Text = txtWeftEMT.Text / txtWarpEMT.Text

'Beta
txtWarpBeta.Text = txtWeftB.Text / txtWarpB.Text

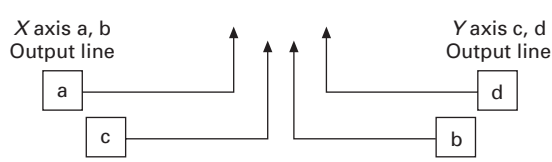
'Clear the picture box ready for a new graph
PicPop.Cls

'Create the graph scale
Math.Scale (–1, 30)–(8, –2)
```




```
'Draw the axis lines

Math.Line (–1, 0)–(8, 0)
Math.Line (–1, 20)–(8, 20)
```



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‘Draw a point for the EMT values
Let Math.FillStyle = 0
Math.Circle (1.8, txtEMTAve.Text), 0.05, QBColor(12)

‘Draw a point for the alpha value
Let Math.FillStyle = 0
*Math.Circle (0.5, txtAlpha.Text * 5), 0.05, QBColor(12)*

‘Join the lines together EMT and alpha
*Math.Line (1.8, txtEMTAve.Text)-(0.5, txtAlpha.Text * 5)*

‘Draw a point for the formability
Let Math.FillStyle = 0
*Math.Circle (3, txtFormability.Text * 5), 0.05, QBColor(12)*

‘Join the line together
*Math.Line (3, txtFormability.Text * 5)-(1.8, txtEMTAve.Text)*

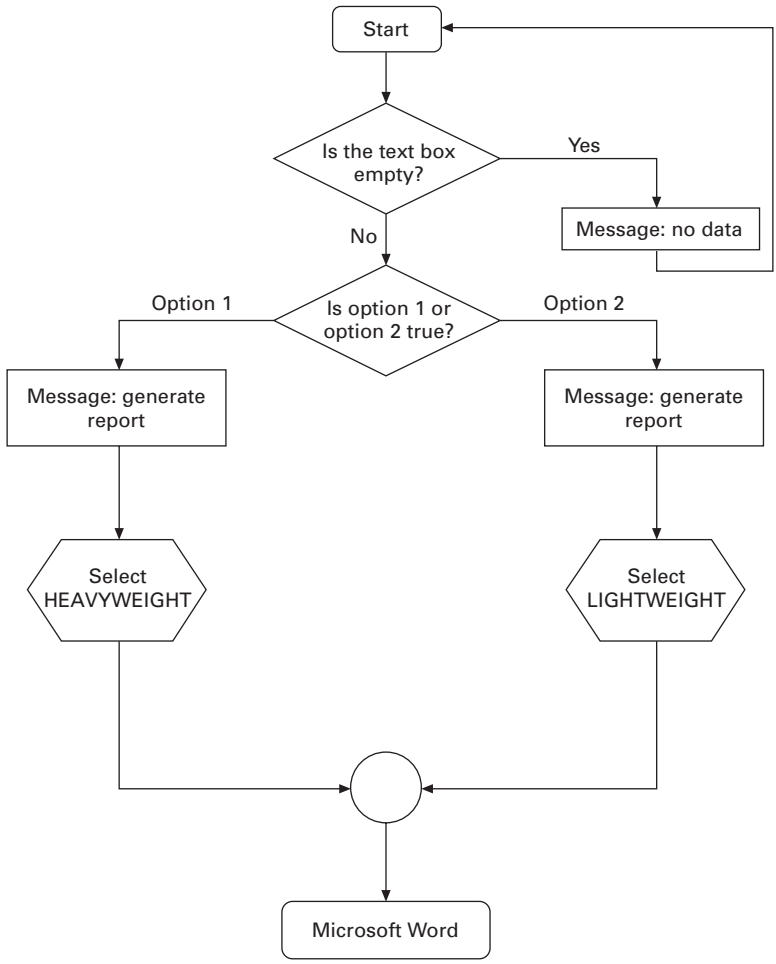
One problem encountered involved values of less than one which would be very difficult to see because they would be almost on the *x*-axis line. In order to overcome this, the smaller values have been multiplied by a factor (*n*), which varies depending on the value and is also built into the ladder areas. A zoom function is also incorporated, which is activated when the ‘**Zoom**’ button is pressed. The code used has many identical features to the code used above. The ‘**Zoom**’ button, however, is disabled until the fingerprint button is pressed.

13.6.9 Report generation algorithm

This consists of two subroutines that are chosen when one of the option buttons is checked. The first subroutine is chosen when ‘**Option 1**’ is selected and the second subroutine becomes active when ‘**Option 2**’ is selected. Both reports are generated in Microsoft Word and consist of a Word document that is called ‘COATS LTD’, which has already been developed to accept the text generated by the software. In order to be able to link to Microsoft Word, a reference is assigned to the software that enables both applications to be glued together. This reference is invoked at runtime and uses the evolving technology of OLE (object linking and embedding). The software utilises the Microsoft Word 9.0 Library. A flow chart of the algorithm is given in Fig. 13.20.

When the ‘**Generate Report**’ button is clicked, a message box is produced asking the user if they want to generate the report. If the option is ‘**Yes**’ then it looks to see if the ‘**Option 1**’ or the ‘**Option 2**’ button is checked. The subroutine for that option is then executed from within the program and the report is generated.

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13.20 Report generation algorithm.

‘Calculate the average values of these text boxes
*txtEMTave.Text = (txtWeftEMT.Text * 0.5) + (txtWarpEMT.Text * 0.5)*
*txtGAve.Text = (txtWarpG.Text * 0.5) + (txtWeftG.Text * 0.5)*
*txtBAve.Text = (txtWarpB.Text * 0.5) + (txtWeftB.Text * 0.5)*

‘Is option 2 true?
Dim Message As String
Dim Buttonsandicons As Integer
Dim Title As String
Dim response As Integer

‘The message of the dialogue box
Message = “Generate Report”
If Option2.Value = True Then

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```
'The dialogue box should have an OK button and a question mark
Buttonsandicons = vbYesNo + vbQuestion

'The title of the program
Title = "FSS"

'Display the dialogue box
Response = MsgBox(Message, Buttonsandicons, Title)

'Evaluate the user's response
If response = vbYes Then
cmdPlaySound2
GoForIt

End If
ElseIf Option1.Value = True Then

'The message of the dialogue box
Message = 'Generate Report'
'The dialogue box should have an OK button and a question mark
Buttonsandicons = vbYesNo + vbQuestion

'The title of the program
Title = "FSS"
'Display the dialogue box
response = MsgBox(Message, Buttonsandicons, Title)

'Evaluate the user's response
If response = vbYes Then
cmdPlaySound2
HitIt

End If
End Sub
```

When the document is executed, the text is inserted in the correct places using the coding structure below.

```
'Set the variable
Dim objword As Word.Application

'Create the object to use for the application, in this case Word
Set objword = CreateObject("Word.Application")

'Set the parameters for insertion of the text
With objword
.Visible = True

'Look for the path of the document in the application path
```

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```
.Documents.Open (App.Path &"\" & "COATS LTD.doc")
'Insert the text from the text boxes in the correct place
.ActiveDocument.Bookmarks("Customer").Select
.Selection.Text = (CStr(txtCompanyName.Text))
.ActiveDocument.Bookmarks("ID").Select
.Selection.Text = (CStr(TXTID.Text))
.ActiveDocument.Bookmarks("Fabric").Select
.Selection.Text = (CStr(txtFabric.Text))
.ActiveDocument.Bookmarks("Date").Select
.Selection.Text = (CStr(txtDate.Text))
```

Text is inserted in the text box on the Fabric Sewability System form.

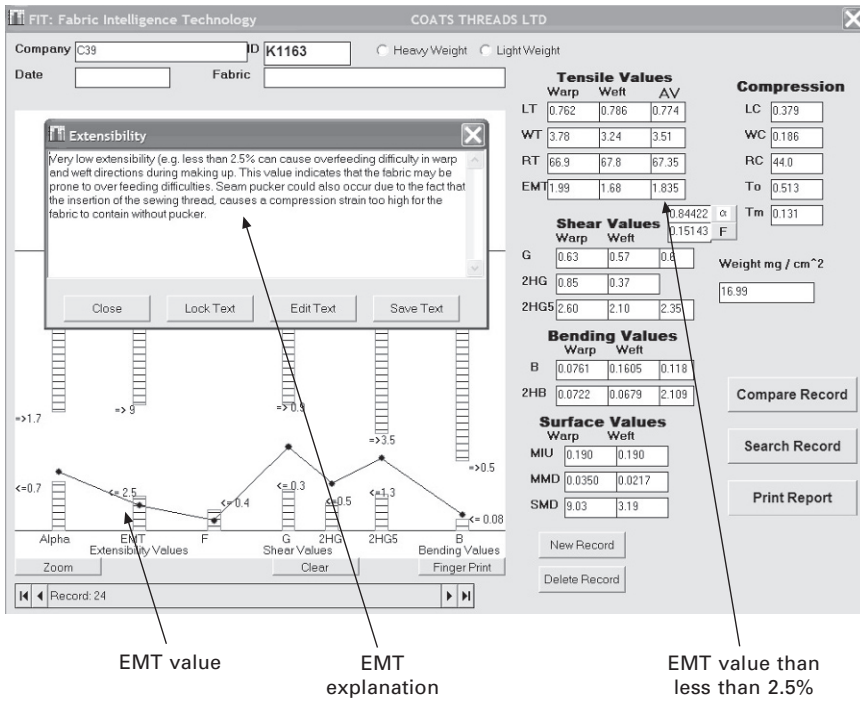
13.6.10 Interpretation of the test values

The KES data values that are analysed by the Fabric Sewability System have been obtained from the *Interpretation Guidelines for KES-FB Test Results (Standard Test Conditions)*[36] and from COATS Sewing Threads Ltd. The explanations that the system uses for report generation have been acquired from reports produced by COATS. The explanations for each data value are triggered by thresholds that have been determined from work done by Marks and Spencer and by the University of Manchester Institute of Science and Technology (UMIST). The values contained in the KES guidelines, however, are concerned more with suiting fabrics. COATS use slightly different values that have been determined through their own in-house testing, and these values are applied to a wider range of fabrics. For the purpose of this research, it is the COATS values that are used in the system.

The thresholds have been concentrated into a smaller number of values for use by the system so that a greater number of explanations can be utilised in order to generate a greater number of reporting options. For example, it is acknowledged in the KES guidelines that for normal woven fabrics, EMT values are typically between 3 and 10%. In addition, very low extensibility (e.g. less than 3%) can cause overfeeding difficulty in the warp/weft direction during making up. The COATS values lie between 2.5 and 9%. The explanation in Fig. 13.21 is triggered when the value drops below 2.5% and gives information on measures to take for this parameter. It can be seen from Fig. 13.21 that both the warp and weft EMT values are below the 2.5% threshold and that the fingerprint point is in the problematical laddered area of the graph.

If both the EMT warp and weft values are high, the system correlates both parameters and generates two alternative explanations. These give the user the option to use the one most appropriate for the report. The second screen reports that both the warp and weft values are high and recommends various

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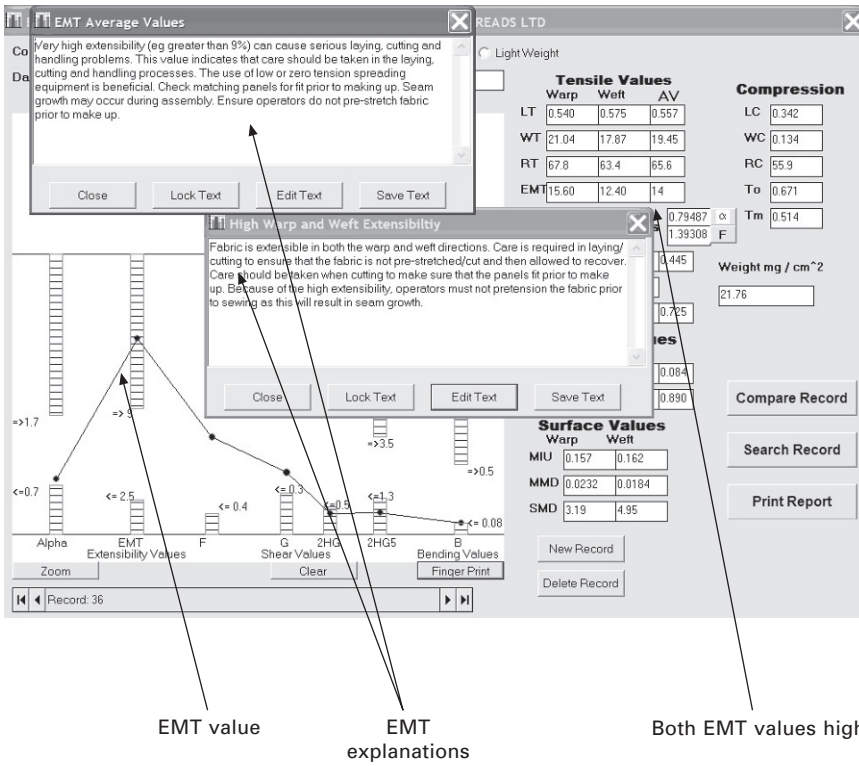
13.21 Explanation of the value EMT.

steps to take in preventing problems when making up. This example can be seen in Fig. 13.22. The system also allows cross-correlation to take place in analysing more than one parameter at the same time. It is stated in the KES guidelines that typical shear values (G) are between 0.6 and 0.9 g cm/degree and for bending stiffness (B) values are between 0.04 and 0.1 g cm/cm. For COATS, acceptable limits are between 0.3 and 0.9 g cm/degree for G and between 0.08 and 0.5 g cm/cm for B. An example of this is given in Fig. 13.23.

13.7 Conclusions

The heightened awareness of garment quality issues associated with the widening global market for production and consumption, accompanied by demands from increasingly critical consumers, can be seen to have led to the drive for more objectivity in production. Properties that had been tested by experienced fabric handlers in the past are now being tested by machines enabling quantification of fabric properties to be undertaken alongside a qualitative approach to determination. However, the deftness of human manipulation and the dexterity of the fingertips when dealing with flexible structures such as textile materials, coupled with the ability to evaluate the

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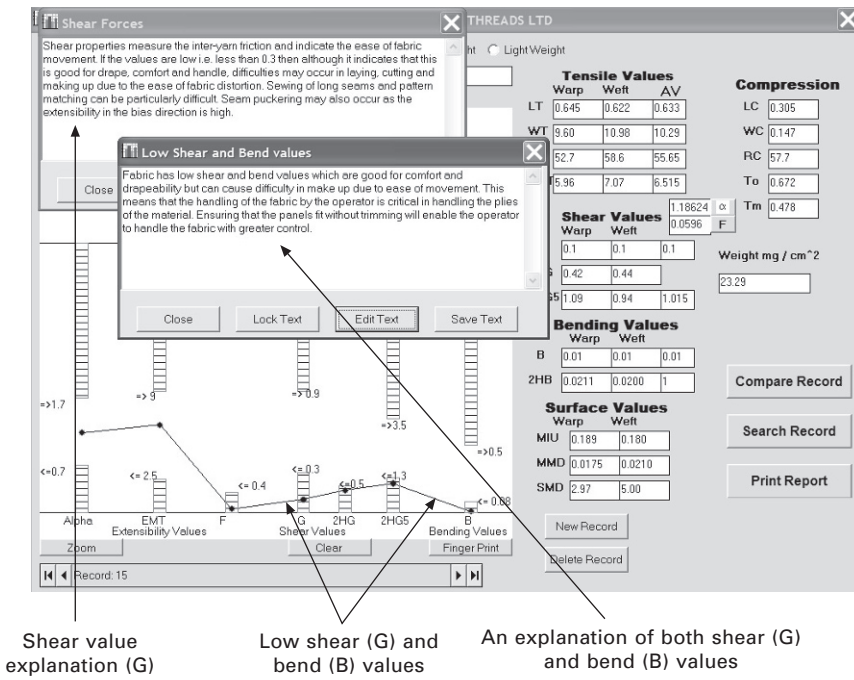
13.22 Correlation between the warp and weft EMT.

suitability of a cloth for a designated purpose, remains a challenge to clothing production manufacturing companies worldwide, as they have difficulty interpreting the subtleties of the results produced by testing machinery.

Fabric objective measurement systems were introduced in order to speed up the process of fabric measurement and increasingly their effect is being applied through research and more importantly in the workplace. The more that subjectivity is associated with the assessment of fabric sewability, the more ambiguous that assessment seems to become. This can be seen if a panel of experts is asked to undertake the difficult task of placing 20 fabrics in order to rank their properties using the criteria already discussed. Although there was close agreement on the stiffness and limpness of fabrics, the longer the exercise continues the less concurrence the experts will achieve for their ranking of fabric properties. The gap between work practice methods and research methods could be seen to be large. Many companies do not have the resources to fund the purchase of an objective measurement system. In fact, many do not know of the existence of such systems at all.

It is apparent that there are major difficulties involved in joining fabrics together at the machine interface using the sewing process. There are, however,

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13.23 Cross correlation of bending stiffness B and shear force value G.

a number of measures that may be taken in order to help alleviate this problem, if not eliminate it completely. These measures are outlined below.

- Developing historical machine settings data for each style and fabric sewn.
- Establishing methods for dealing with seam pucker, understanding its causes and steps that may be taken to counter it.
- Giving technicians and production staff greater understanding of the properties associated with a fabric. This includes knowledge of fibres, yarns, yarn twist, frictional properties, shear forces, extensibility and bending rigidity.
- Using the Fabric Sewability System to correlate the results from the Kawabata system with the experimental measurement of fabric variables so that a low-cost method can be applied to fabric testing.
- Extending the use of fabric objective measurement systems in fabric manufacturing companies in order to enable warnings of material instability to be given before despatch at fabric apparel manufacturing companies.

Further research should be performed and a settings database could be created to determine the optimum sewing conditions for each type of fabric sewn.

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The use of low-cost instrumentation for machine optimisation should be promoted; such equipment currently exists for measuring thread tensions and strain gauges, and is inexpensive to purchase. Sewing tests need to be performed in order to determine the most desirable machine settings for the material to be sewn. Fabrics may be ranked in a similar way according to their sewability properties. The instrumentation would be used to measure optimum thread tensions and presser foot pressures. These would be recorded and kept on a database to be used again if the manufacturer processes the same style and fabric at a later date. In addition, machine settings such as feed height, type of feed mechanism and handling techniques would be recorded. All of these parameters would be contained within the Fabric Sewability database. One of major areas in which this system could be used would be in the fabric manufacturing companies, in order to give advanced warnings on fabric sewability. A batch of fabric could be woven and then tested on a fabric objective measurement system linked to the Fabric Sewability System. The resultant testing and report from the batch of fabric tested could then enable fabric companies to modify processes or correct potential problems before they reach the clothing manufacturer.

The Fabric Sewability System may also be developed and adapted to work with the other main fabric objective measurement systems currently assessing fabric properties, such as the FAST system. Further work needs to be done to gain a deeper understanding of the cross-correlation of fabric parameters and of their significance in garment sewability. This would facilitate the design of pertinent trials to test the practicality of having machine settings for particular garment make up processes. This should be taken up in association with the garment manufacturer.

13.8 References

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