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A Web-based Design Support System for Fashion Technical Sketches

Jie Xu, P.Y. Mok*, R.W.Y. Yee, C.W.M. Yuen

Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hong Kong
* Corresponding author: E-mail: tracy.mok@polyu.edu.hk
Telephone: +852-27664442

Abstract

Purpose

To better respond to today's volatile and changing fashion market, the purpose of this paper is to develop a Web-based design support system that enables users to design realistic and interesting skirts in the form of technical sketches over the Internet.

Design/methodology/approach

The proposed system mainly consists of a sketch representation and composing method (SRCM), a graphic user interface (GUI) and a controller. The SRCM is implemented at the server end that generates technical sketches according to user defined parameters and features via the Web-based GUI at the client side. The controller manages the workflows between the server and the clients.

Findings

To evaluate the effectiveness of the proposed system, a survey was conducted by inviting 30 subjects (professional designers or undergraduate students studying fashion design) to have trial run of the system in Hong Kong and in the USA. Positive comments and feedbacks were received, and valuable suggestions were also obtained in regard to the prototype system.

Originality/value

Compared with traditional Computer-Aided Design (CAD) systems, the proposed system is more effective and easier to operate as users can create technical sketches in accurate proportions with simple computer operations in a few mouse clicks. Besides, the output sketches are fully compatible with most commercial CAD software. The system is developed based on Web technologies, thus fashion sketches can be easily designed using any computer connected to the internet; it can be implemented on Android or iOS platform in the future.

Keywords

Internet, CAD, Computer aided design, Fashion sketch design, Web-based

1. Introduction

Fashion is important to the world's economy and the global apparel market was valued at US$1.7 trillion in 2012 (Fashionunited.com, nd). Following sustained growth in the 1990s, the fashion industry has undergone many changes over the past two decades. Despite the steady rise in the indexes of all prices, the index of clothing and footwear has experienced price deflation since the 1990s (CSO, 2005). UK customers now pay 30-50 per cent less than ten years ago for a same clothing or footwear product (Hines, 2006). Price deflation and continual increases in manufacturing cost are narrowing the profit margins of fashion companies on one hand. Today's customers are interestingly complex and more powerful on the other hand. They expect personalised products with lower prices, better quality and shorter production lead time. These realities combined with intensified competitions have put immense pressures on the fashion industry.

In order to supply customers with the right products in the right place at the right time and at affordable prices, it is necessary to investigate the process of fashion product development. The generic fashion design process is phased with a series of steps including research, design development and manufacturing (Sinha, 2001). As shown in Figure 1, the phase of design development involves two processes - sketch design and sample development.

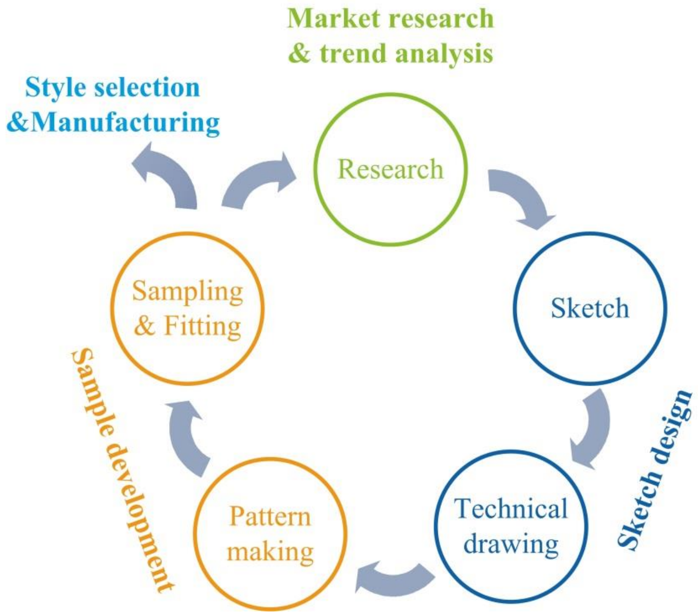


Figure 1 Fashion product development cycle

Among the many technology enablers, computer aided design (CAD) is one of the most widely adopted tools to improve efficiency and effectiveness of the product development process. Examining the product development cycle (as shown Figure 1), traditional CAD systems mostly support the downstream manufacturing, such as grading and marker planning. In recent years, a large number of research studies, mainly by the computer graphic community, were reported on virtual 'sampling' that 2D patterns are virtually sewn up around 3D human models to form three dimensional garments (Hinds and McCartney, 1990; Okabe et al., 1992; Luo and Yuen, 2005; Durupynar and Gudukbay, 2007). Cloth simulation can be geometrical or physical-based. Geometrical-based simulations, such as Ng et al. (1995) Igarashi and Hughes (2006), usually provide fast results, but they do not consider the physical properties of the cloth, so could not reproduce the dynamics of clothes (Volino et al, 2004). Physical-based approach can simulate more realistic and dynamic effects. Physical-based cloth simulation is more accurate as they take into account structural properties of textiles; the dynamic/mechanical laws derived from discrete dynamics, elasticity theories, or fluid dynamics that governing cloth behaviour and its interaction with external environments (Kang and Kim, 2000; Metaaphanon and Kanonchaiyos, 2005). In the past, many methods were proposed that can be classified as continuous physics-based and discrete physics-based methods, focusing on realism and computational efficiency, respectively (Han and Stylios, 2009). The continuous physics-based methods provide a rigorous representation of cloth based on continuum mechanics and usually adopt finite element or finite difference model to achieve solution, such as Terzopoulos et al. (1987) Volino and Magnenat-Thalmann (1995), Sze and Liu (2007). Teropoulos et al. (1987) modelled cloth's surface deformation by continuous Lagrange equations as a set of displacements from equilibrium positions. Eischen et al. (1996) used non-linear shell theory, and Li and Volkov (2005) described cloth immersed in a quasi-stationary viscous fluid from a fluid dynamic point of view. In these formulations, nonlinear finite element (FE) procedure was used to obtain the system equations. The goal of FE methods was not to model any particular deformable material (cloth) accurately, but was instead to create physically based models for computer animation useful for producing qualitatively similar behaviours without requiring a prohibitive number of computations (House and Breen, 2000). The continuous methods usually suffer from instability problem and highly computational expensive. On the other hand, discrete physics-based methods represent cloth as a grid of particles interacting with each other and the outside world in accordance with either

Newtonian dynamical laws (force-based approach) (Petrak et al., 2006; Hauth and Etzmuβ, 2001), or Lagrangian dynamical laws, or energy minimization criteria (energy-based approaches) (House and Breen, 2000). The mass-spring system (also known as the particle system) is widely used due to its low computational complexity and simple implementation (Breen et al., 1994; Provot, 1995; House et al., 1996; Fontana et al., 2005; Han and Stylios, 2009). The main issue of the mass-spring model is accuracy, because the physics of the cloth deformation is approximated. Mesh topology affects the cloth simulation because it represents the approximation in discrete physics-based methods. Several meshing and remeshing methods have been proposed (Lienhardt, 1994; Praun and Hoppe, 2003; Attene and Falcidieno, 2006). Liu et al (2010) investigated various mesh topologies and suggested an optimal pipeline for the preparation of mass-spring model in scanned garment reconstruction.

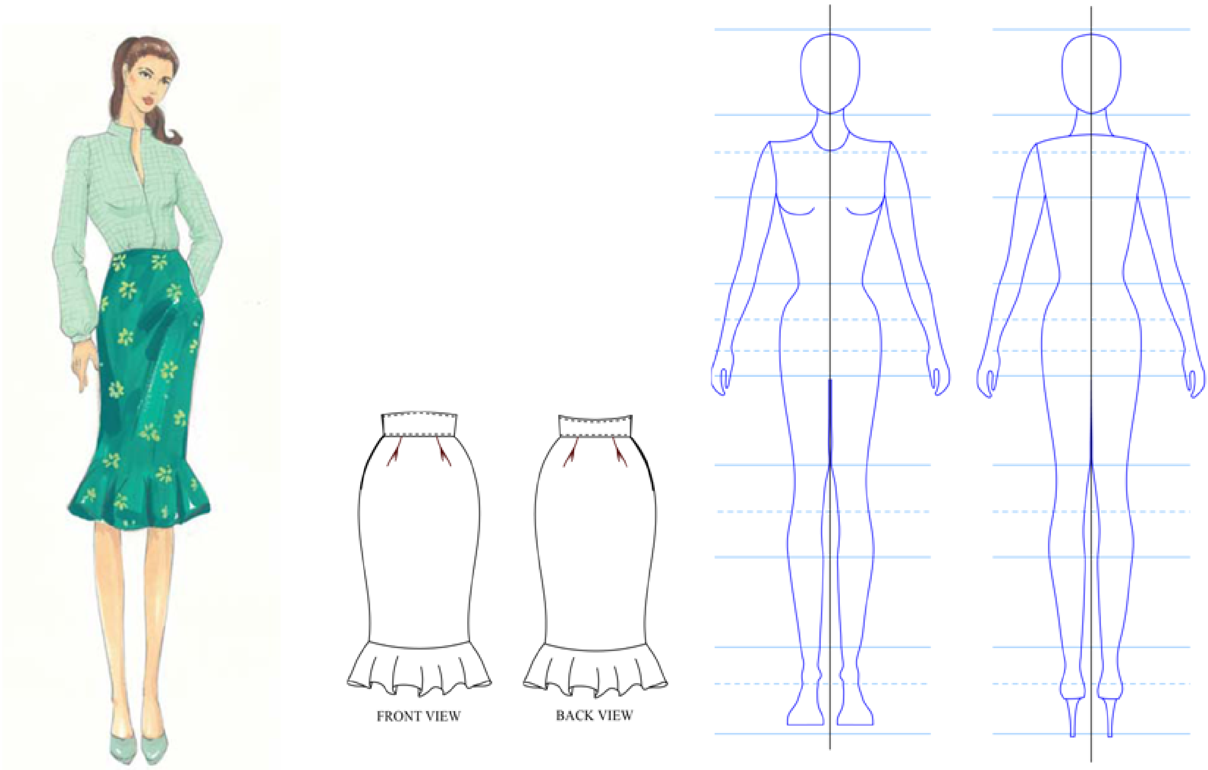
Other than virtual sampling, other researchers focused on pattern design or patternmaking. Hu et al. (2008) proposed an interactive co-evolutionary CAD system for the parametric pattern design of a leisure shirt. Hu et al. (2009) used neural network and immune algorithm to generate garment patterns. Chen et al. (2009) used fuzzy logic to optimise garment pattern design. Lu et al. (2010) introduced an expert knowledge base in assisting customised pattern making. Guo et al. (2011) provided a detail review on artificial intelligence applications in fashion industry.

Examining the literature, it is found that sketch design is a relatively unexplored area in the research supporting product development process. In the fashion industry, designers mainly use commercial CAD software, such as Adobe Illustrator™ or CorelDraw™, to create sketches.

With such software, sketches can be recorded and edited easily, but creating a new style from scratch is still time consuming that designer has to draw stroke by stroke. A recent survey reported that Hong Kong designers are longing for new and user-friendly design support systems to speed up their design operations (Chow, 2012).

To cope with the mounting stress of the accelerated design cycle, some companies provided special digital fashion libraries, such as SnapFashun™ (snapfashun.com, nd), so that designers can invoke components in these libraries to compose new styles. Recently, Mok et al. (2013) developed a design system for general customers to create fashion sketches using evolutionary computational techniques. Another interesting work was reported by Wan et al. (2014) that shape deformation techniques were used to generate realistic fashion sketches from standard technical sketches. In the apparel industry, there are two main types of sketch, fashion illustrations and technical sketches (flats), as shown in Figure 2. Fashion illustrations are figure drawings; they show merchandise on figures and with accessories, presenting to the target customers how merchandise can be arranged into groups and what seasonal themes are being followed. Wan et al.'s (2014) system converts technical sketch into fashion sketches with all garment details and textures, i.e. fitting the same garment on different fashion figures in different poses.

Among the different types of sketches, technical sketch (also called 'flat') is the most important one. Flats are drawn to scale, including sewing and construction information. Flats usually involve both a front and a back view, and are often developed with the help of croquis – human figure templates (see Figure 2(c)). Technical drawings are specific, precise, and they are part of the product specification, being used to explain the design with the production team for patternmaking and prototype development. Any mistake in the ‘flat’ would cause problems in the final garment.



(a) Fashion Illustrations (b) Technical Sketches (Flats) (c) Croquis (human figure template)

Figure 2 Illustration of fashion illustration, technical sketch and croquis

In this paper, we propose a Web-based sketch design system that supports designers creating technical sketches of ready-to-wear styles efficiently and effectively. The system enables designers to easily create interesting sketches by selecting their preferred style features with a few mouse clicks, on any computers connecting to the internet. Compared with other existing CAD systems, the proposed system has the following characteristics/advantages, making it more effective and easier to operate.

- *Fully compatible design elements.* Unlike other digital fashion libraries, e.g. SnapFashun^{TM}, the proposed system arranges selected style elements/design details with the silhouette/shape automatically, demanding nil manual adjustments. The interdependence among the features/details and silhouette/shape are well defined to ensure mutual compatibility. On the other hand, the features/details or silhouette/shape can vary by adjusting input parameters. These variations do not influence the compatibility among them. In section 6 results and discussion, examples will be presented to illustrate this advantage of the system.
- *Adaptation for customised human model template.* Each fashion company has its own set of croquis for sketch design; such croquis set usually have a front view and a back view of the human body shape, and they are prepared based on target customers' body proportions and shapes (see Figure 2(c)). Unlike existing digital fashion libraries that all feature details have fixed shapes, the proposed system can automatically create different sketches in accordance with the input human model templates. The system generates sketches that dynamically 'fit' to the input croquis, and avoids tedious adjustments when croquis templates are changed.
- *Parameterised and compatible output sketches.* The output sketches of the system are parameterised, which means the sketches contain explicit and precise design information. For example, the number of darts, the position, the length and the shape of the darts. It minimises style misinterpretation and eases the communication among different parties along the fashion supply chain. The system can be easily integrated with the pattern design

system (Wu, 2012) to realise truly customised clothing design. In addition, the system output sketches are in the file format of drawing exchange format (DXF), and the output sketches can be imported and further processed by most commercial CAD. It dramatically shortens the time needed to create a sketch and enables easy style editing.

- *Web technologies.* The system is developed based on Web technologies. During the last decade, the proliferation of Web-based technologies may have given the impression of wide-spread changes in industrial practices. A Web-based design system supplies time and place ubiquity to users, making the whole business operation seamless. It is technically challenging to have CAD systems developed on the Web. In this system, Web-based technologies are used, and thus it facilitates integration and remote cooperation along the fashion supply chain. It also empowers customers to create more personalised designs. Software and maintenance costs are reduced for a Web-based system; any update in server-side seldom influences the users in the client side.

The rest of the paper is organized as follows. The details of the proposed Web-based design support system will be explained first. Then, some results generated from the proposed system will be presented. A system evaluation will then be reported and the system's strengths and future development will be discussed. Lastly, a concise conclusion will be given.

For the sake of simplicity, skirts are used as examples in this paper to illustrate the proposed method. Although the composition of skirts is not too complex, skirts involve diversity of style changes, and it is a good example to illustrate the relationships among different design elements, for example, silhouette (skirt shape) and design features (pleats/darts). Nevertheless, it is important to note that sketches of other fashion products, such as trousers and blouses, can also be created by the same method.

2. Methodology overview

The framework of the Web-based design support system is shown in Figure 3. The main parts of the system include a sketch representation and composing method (SRCM), a Web-based graphic user interface (GUI), and a controller. The SRCM is the core part of the system, which can automatically generate design flats, in vector graph format, by selecting design elements and defining the respective parameters from the Web-based GUI. The controller manages the workflow of the system, bridging between the SRCM and Web-based GUI.

The system is developed using C# language based on Teigha.NET^{TM} development kit (opendesign.com). It creates sketches in vector graph files and exports in DXF file format that can be supported by most commercial CAD systems. The system is developed on apache server. HTML5 technology is used in Web interface design to allow display of scalable vector graphics content (i.e. sketches) on client browsers.

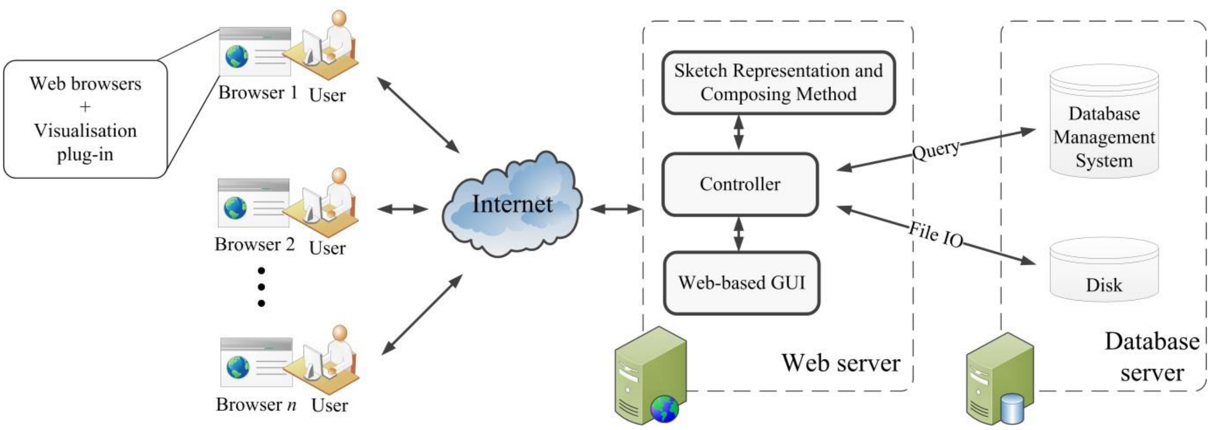


Figure 3 The framework of the Web-based design support system

3. Sketch representation and composing method (SRCM)

Figure 4 shows that the SRCM includes three components: a parametric design model, a style database and a design sketch composing engine. There are two inputs to the SRCM: first, style elements and their parameters defined by users via the Web-based GUI; second, 2D human model templates which are pre-defined in the system or input by users. SRCM outputs technical sketches of both front and back views; such sketches fit to the input 2D human model templates.

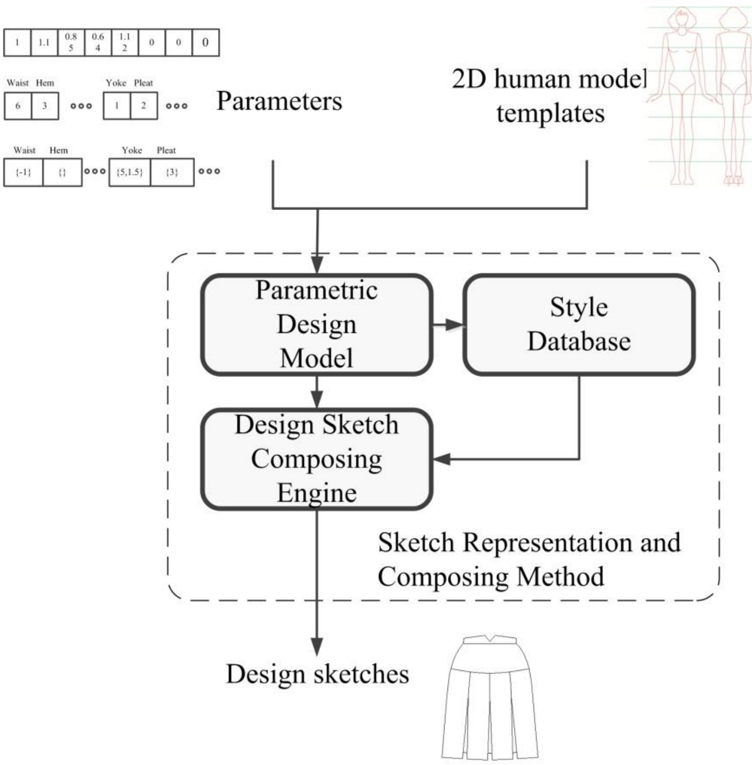


Figure 4 The sketch representation and composing method (SRCM)

3.1 Parametric design model

In the parametric design model, most design elements for ready-to-wear styles are categorised in to three levels. The first level defines the silhouette or the shape. The second and the third level provide key style elements and design details, respectively. The main difference between the key style elements and the design details is whether they affect silhouettes or not. The key style elements are necessary to introduce in order to achieve the silhouette defined in the first level, while the design details do not alter the silhouette but only provide decorations or functions. Following the three-level structure, different design elements can be classified, the design elements of skirts are shown in Figure 5. Based on the classification, either complicated or simple designs can be represented as a combination of the three-level design elements.

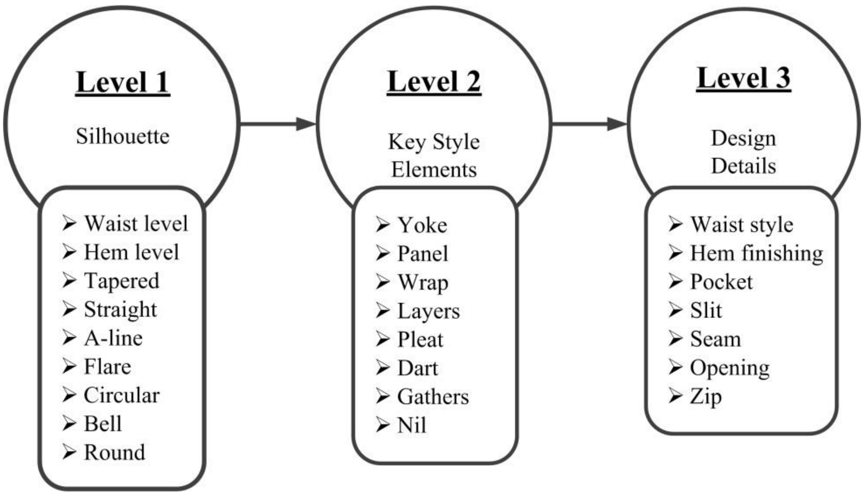


Figure 5 The three-level structure of design elements for skirts.

The first level of silhouette defines the general shape of a fashion product and it also determines design elements in other levels. Taking skirts as examples, eight parameters $\boldsymbol{S}$ = [S_1

S_2 … S_8] based on the knowledge of fashion design and patternmaking are used to illustrate the silhouette, as shown in Equation (1) and Table 1

$$Silhouette(Shape_1, Shape_2, ..., Shape_N) = f^{(S)}(S_1, S_2, ..., S_8) \quad (1)$$

where N is the number of shape groups. A more detailed description on the mathematical definition of each parameter $\boldsymbol{S}$ is shown in Appendix 1.

Table 1 Silhouette parameters

Parameters	Description	w.r.t. human template
S_1	Symmetry information	
S_2	Waist level parameter	Vertical position
S_3	Hem level parameter	Vertical position
S_4	Hip width parameter	Horizontal position
S_5	Hem width parameter	Horizontal position
S_6	Complex shape indicator	
S_7	Style line parameter	Vertical position
S_8	Style line width parameter	Horizontal position

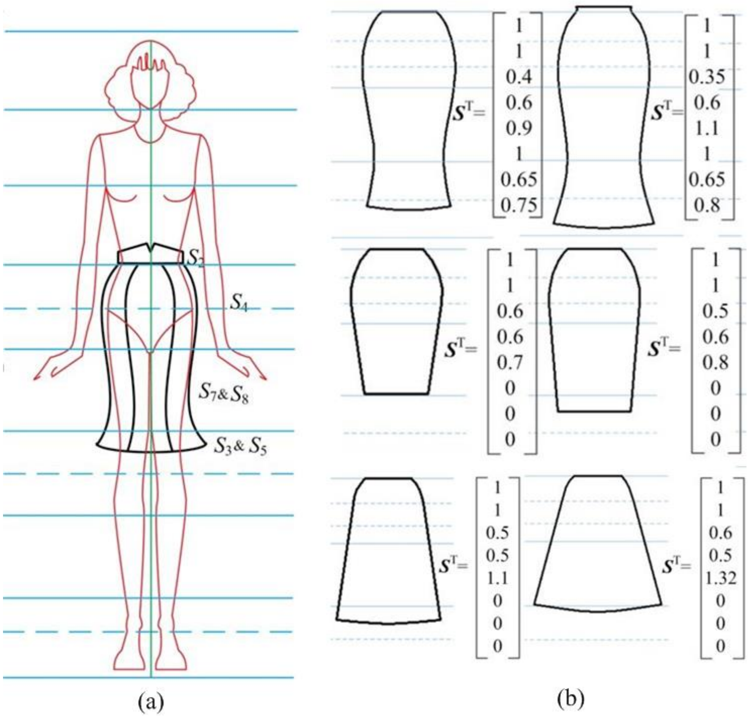


Figure 6 (a) Sketch are overlain on croquis; (b) example silhouettes and parameters $\boldsymbol{S}$

These silhouette parameters ***S*** give the key proportions in skirt design (see Figure 6(a)) and such proportions are defined as ratio parameters to some standard measurements, for instance, the body waist width, of the given template model or croquis.

By defining different values of the eight silhouette parameters, various shapes can be obtained. Figure 6(b) shows some example silhouettes and relevant silhouette parameters ***S***. The definition of these silhouette parameters ranges will be explained in later section 3.2 style database. For easy comprehension of designers, silhouettes are categorized into seven shape groups in this study, including A-line, flare, straight, tapered, circular, round/bubble, and bell.

A set of classifiers $\boldsymbol{C} = [C_1\ C_2\ \ldots\ C_7]$ (as shown in Table 2) are calculated according to the eight silhouette parameters ***S***, and these classifiers will be used to define next level of design elements. The mathematical definition of ***C*** is detailed in Appendix 2.

$$ShapeClassifier\,(C_1,C_2,...,C_7)=f^{\,(C)}\,(S_1,S_2,...,S_8) \qquad (2)$$

Table 2 Shape classifying parameters

Parameters	**Description**
C_1	Proportion parameter
C_2	Design ease at hip
C_3	Hip curve shape classifier
C_4	Above hip shape classifier
C_5	Below hip shape classifier
C_6	Design ease at style line level
C_7	Below style line level shape classifier

In the three-level structure, the second level defines key style elements. The silhouette defined in the first level needs to be realized by the incorporation of these key style elements. The key style elements are thus defined by shape classifiers ***C***:

$$KeyStyleElements(DF^{(1)}, DF^{(2)}, ..., DF^{(k)}, ..., DF^{(H)}) = f_2^{(DF)}(C_3, C_5 / C_7) \quad (3a)$$

where $DF^{(k)}$ (k = 1, 2,…, H) are H different categories of key style elements, including yoke, panel, wrap, layers, pleat, dart, gathers and nil. For each category of key style element $DF^{(k)}$, there are a total number of M feature styles, denoted as $DF_i^{(k)}$, where i = 1, 2, . . . , M. For example, $DF^{(1)}$ represents yoke, $DF_2^{(1)}$ indicates the second kind of yoke style. For each kind of key style element $DF_i^{(k)}$, a number of n parameters (denoted as $DFT_{ij}^{(k)}$, where j = 1, 2, …, n) are used to describe the characteristics/feature details of the style feature subgroup, such as position and size information, by the following equation

$$DesignFeatureDetails(DFT_{i1}^{(k)}, DFT_{i2}^{(k)}, ..., DFT_{in}^{(k)}) = f^{(DFT)}(DF_i^{(k)}) \quad (3b)$$

Figure 7 shows an example yoke style (the i-th style of yoke), which has two parameters P_1 and P_2. P_1 defines the position of the yoke line and P_2 specifies the shape of the yoke line. Therefore, P_1 and P_2 are $DF_{i1}^{(1)}$ and $DF_{i2}^{(1)}$ of this style of yoke.

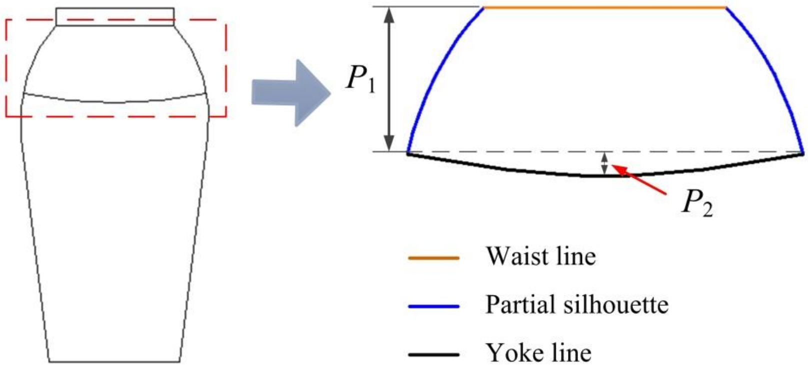


Figure 7 An example illustrating one kind of yoke (key style element) style

Design details, which would not alter the silhouette but provide decorative details or additional functions for the style, are classified as the third level of the design model. The third level design elements are defined by the design elements of the upper levels. Equations (4) to

(8), parts (a) define the relationship among these levels. Parametric models are given to describe the characteristics of the third level design details, as shown in Equations (4) to (8), parts (b). Detail explanation of equations (4) to (8) are given in Appendix 3.

$$WaistStyle\,(W_1, W_2, ...) = f^{(W)}(S_2, DF) \quad (4a)$$

$$WaistStyleDetails(WT_{i1}, WT_{i2}, ...) = f^{(WT)}(W_i) \quad (4b)$$

$$HemFinishing(HF_1, HF_2, ...) = f^{(HF)}(DF, C_5 / C_7) \quad (5a)$$

$$HemFinishingDetails(HFT_{i1}, HFT_{i2}, ...) = f^{(HFT)}(HF_i) \quad (5b)$$

$$Slits(SL_1, SL_2, ...) = f^{(SL)}(S_3, C_5, DF) \quad (6a)$$

$$SlitsDetails(SLT_{i1}, SLT_{i2}, ...) = f^{(SLT)}(SL_i) \quad (6b)$$

$$Pockets(P_1, P_2, ...) = f^{(P)}(DF) \quad (7a)$$

$$PocketsDetails(PT_{i1}, PT_{i2}, ...) = f^{(PT)}(P_i) \quad (7b)$$

$$Opening(O_1, O_2, ...) = f^{(O)}(DF, W\ ) \quad (8a)$$

$$OpeningDetails(OT_{i1}, OT_{i2}, ...) = f^{(OT)}(O_i) \quad (8b)$$

According to the three-level parametric model, different combinations of the three-level design elements can construct various parametric styles. It is important to note that the three-level parametric model is developed after a substantial review of the fashion design and patternmaking literature, and various online resources of design sketches (wgsn.com; peclersparis.com).

3.2 Style database

Following the three-level sketch representation model, a style database is developed to record different levels of design elements. Three types of design element were defined in the database, which is consistent with the three-level structure, as shown in Figure 5. In the database, the first type of design elements defines the skirt silhouette, including symmetry information, the waist level, the hem level and the shape. Various skirt shapes are categorised into seven groups, which together with different waist levels and hem levels can be defined by silhouette parameters ***S***, as shown in Figure 8. The classification method for silhouettes is listed in Appendix 2. The value ranges of silhouette parameters ***S*** for different groups of shape, waist level and skirt length (hem level) are defined in Table 3, based on the design knowledge of skirt design. The second and third columns of Table 3 show the value ranges of ***S*** and the relevant meaning of these value ranges, respectively. The parameters and value range of these parameters are defined, tested and verified by expert designers, and such information is recorded in the database.

Table 3 The value ranges of parameters ***S***

Parameters	**Value ranges**	**Remarks**	**Types**
S_1	1, 0	1- Symmetric silhouette and design details; 0- asymmetric silhouette and design details.	Symmetry information
S_2	[0.5, 1.5]	1 Normal waist; 1~1.5 High waist; 0.5~1 Low waist	Waist level
S_3	[0.17, 2.5]	The smaller the value, the longer the skirt	Hem level
S_4	[0.5, 0.95]	The smaller the value, the wider the hip width	Shape parameters

S_5	[0.7, 2]	The greater the value, the wider the hem width
S_6	1, 0	1- Additional bit to define ***style point*** for bell and round shape; 0- Shape with straight side seam from hip to hem.
S_7	[0.2, 0.9]	***Style point*** level ratio. If S_6 =1, S_7 is valid. The greater the value, the lower the ***style point***
S_8	[0.7, 1.6]	***Style point*** width ratio (*styw*). If S_6 =1, S_8 is valid; if *styw*<1, bell shape; *styw*=1 straight; *styw*>1, round

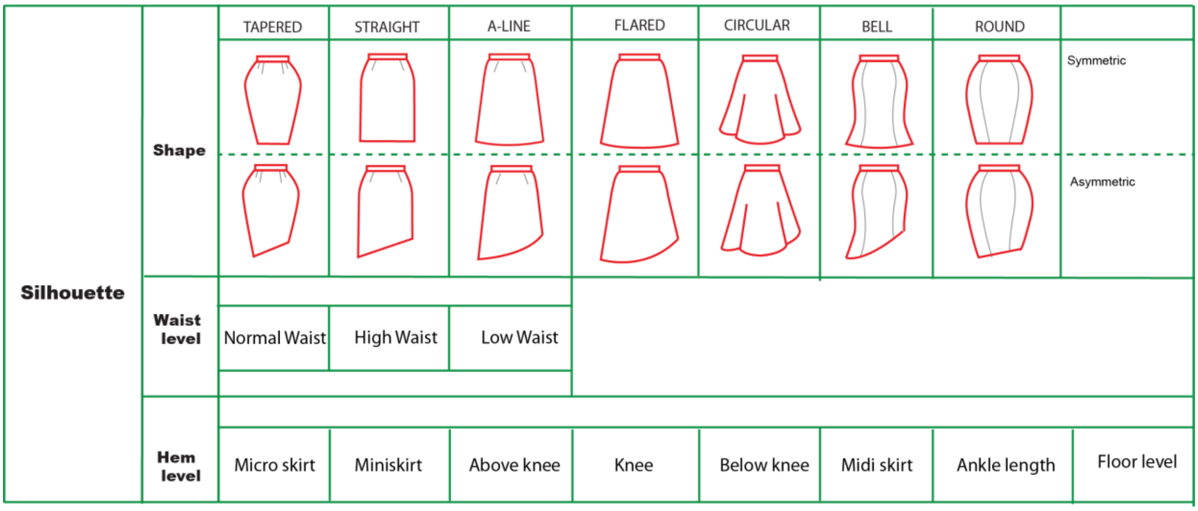


Figure 8 Silhouette feature

The second type of design elements in the style library is key style elements, including yokes, panels, and pleats. Each type of key style elements includes a number of feature subgroups. Figure 9 shows some examples of key style elements and the relevant subgroups of those features.

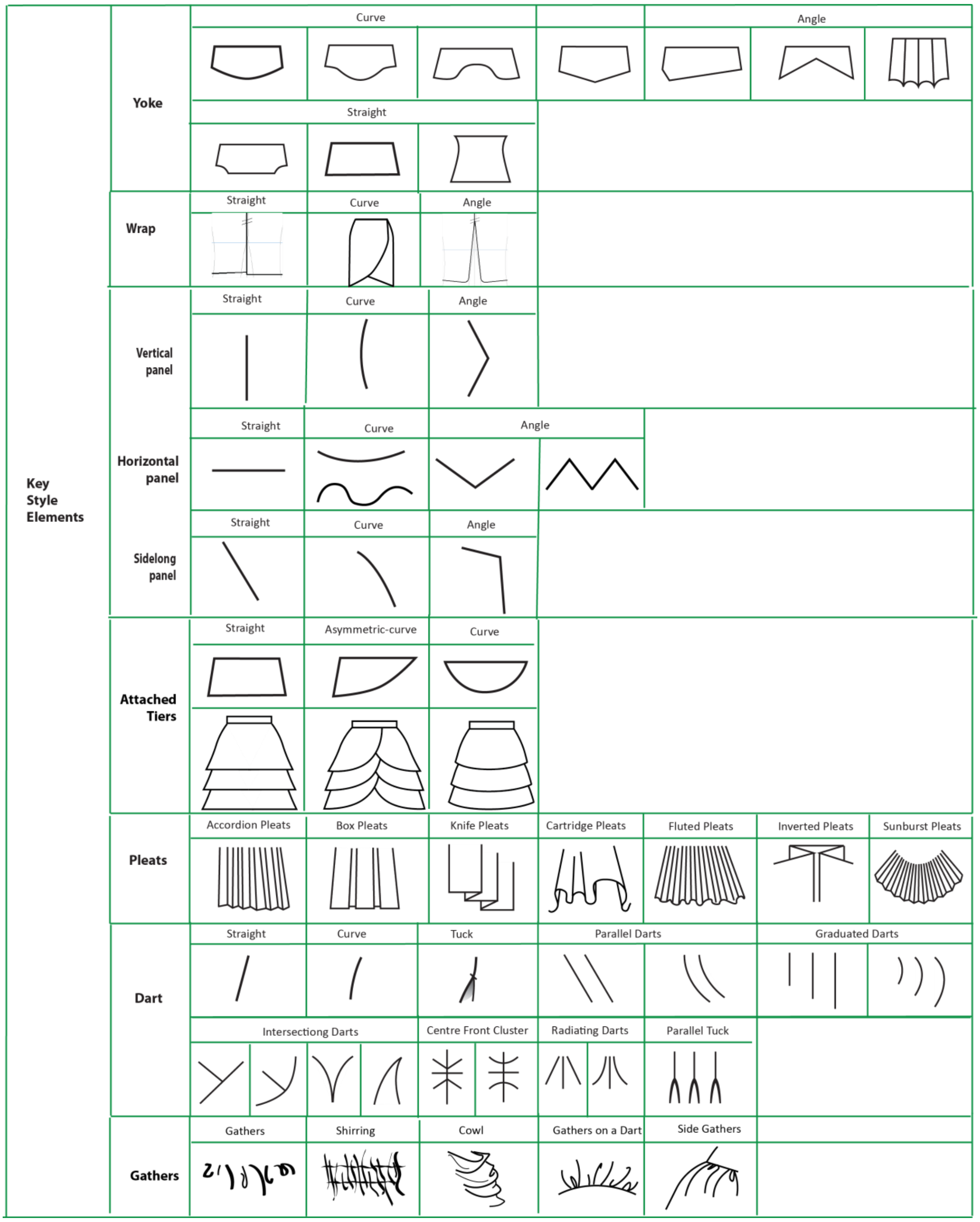


Figure 9 Key style elements

The third type of design elements in the style library is design details, and they are also classified in subgroups. For example, waist is classified into 13 style subgroups and hem style is classified into 11 style subgroups (see Figure 10 for some example elements). Some third-level design elements with complex details, such as pockets, are defined in the style library as block objects. To use this kind of design elements (design details), the block is inserted to the skirts based on position and size parameters. It is important to note that the style database can be expanded by adding new subgroups of design element, or even introducing new categories of key style elements or design details.

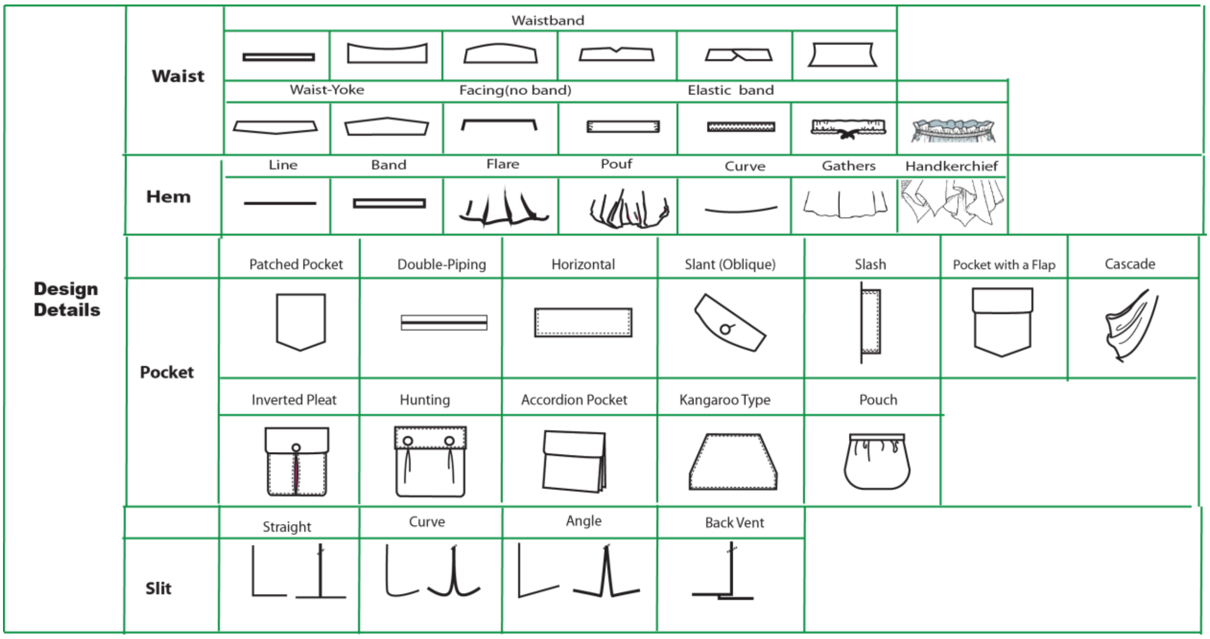


Figure 10 Design details (examples)

A skirt style with all design element parameters is recorded in a three-array data structure. The data structure is used to record user input via the Web-based GUI and communicate with the style database. In three-array data structure, the first array indicates the design silhouette, corresponding to silhouette parameters ***S***; The second and third array are respectively for other selected key style elements and design details and their corresponding parameters. Every key style element or design detail has several style subgroups, and each style subgroup is defined by a few parameters. Therefore, the second array tells which subgroups of the design elements are included in the design. Users select and define the parameters via the Web-based GUI. In the style database, each design element is defined with a default set of parameters. All data definitions are hidden from users, who select and adjust the parameters to alter specific design characteristics via the Web-based GUI. Figure 11 shows an example skirt and its corresponding three-array data structure.

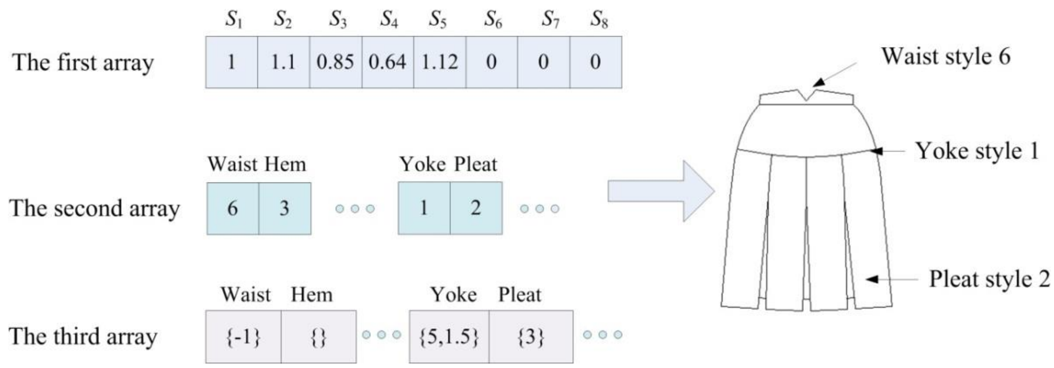


Figure 11 An example skirt and its data structure defined in the Web-based sketch design support system

3.3 Design sketch composing engine

The third component of SRCM is a design sketch composing engine, which is developed to construct design sketches based on selected design elements. The sketch composing engine consists of two types of algorithms, namely silhouette drafting algorithms (SDA) and adaptation and attachment algorithms (AAA) (see architecture in Figure 12). The system first reads in a human template model/croquis; some key landmarks on the model/croquis (Hwang, 2004), as well as the body outline curves necessary for sketch design, are defined. Next, the skirt silhouette shape is sketched based on the body information and a set of silhouette parameters $\boldsymbol{S}$ using SDA. Later, level 2 key design elements and level 3 waist styles and hem finishing are sketched in an optimised sequence, based on the parametric models. Lastly, other level 3 design elements are sketched. AAA is used in this process.

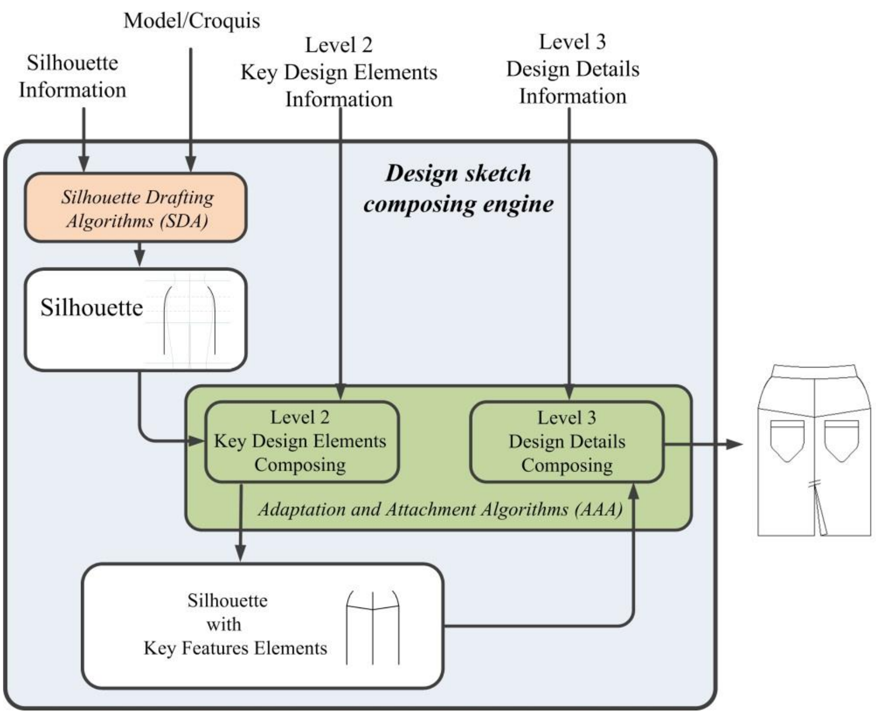


Figure 12 Design sketch composing engine architecture

3.3.1 Silhouette drafting algorithms (SDA).

The silhouette curve is composed of one or several splines (lines), and the number of splines is related to the skirt shapes. SDA first calculate the maximum number of splines by:

$$MaxNum = NumFunction(Silhouette(Shape) = f^{(S)}(S_1, S_2, \ldots S_8)) \quad (9)$$

where *Silhouette(Shape)* is defined by Equation (1) and $\boldsymbol{S}$= [S_1 S_2 ... S_8] are silhouette parameters. The detail explanation of equation (9) is given in Appendix 4. Next, SDA construct silhouette curve using the silhouette parameter $\boldsymbol{S}$ and Equation (9) by calling a sequence of low-level geometrical operations.

One example is illustrated in Figure 13. The silhouette parameters ***S*** classify the skirt shape as 'Straight' by Equation (1). SDA then decide that the silhouette curve is composed of one spline and one line by Equation (9) and calculate the positions of Points A, B and C accordingly. 'TA1A' and 'TA1B' denote the tangential angles for 'Spline 1' at 'Point A' and 'Point B', respectively. These parameters are defined based on silhouette shape and parameters ***S***.

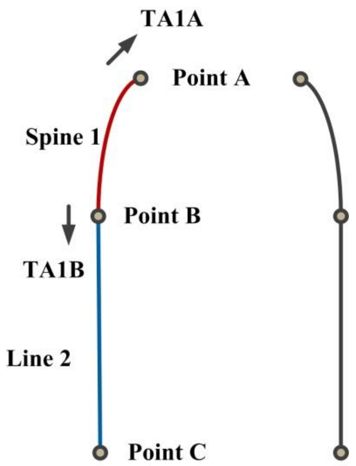


Figure 13 Silhouette curve

3.3.2 Adaptation and Attachment Algorithms (AAA).

As defined in Equation (3), every design element comprises several parameters; these parameters can be classified as position, variable and inherent parameters. Design elements are sketched by two types of construction rules: adaptation rules and attachment rules. The adaption rules work in a similar way as SDA, see Figure 14. It first calculates all the key points of the design element using position, variable and inherent parameters; inherent parameters record information of the upper level features, e.g. the silhouette curve. Next, it composes the design element by calling a sequence of low-level geometrical operations for modifying and/or drafting feature curves using Teigha™ development kit (opendesign.com). Adaptation rules allow flexible construction of design elements. Another type of rules–attachment rules are used when the design elements are first recorded as object blocks in the style database; each block is characterised by a size and a pick point. Attachment rules do not alter the design elements except size scaling; attachment rules also refer the pick point to a target position. The two types of rules are used together to compose complex design elements.

To compose design elements, adaptation and attachment algorithms first decode the information of the parametric design model and invoke the right design element in the style library by applying the relevant adaptation rules or attachment rules.

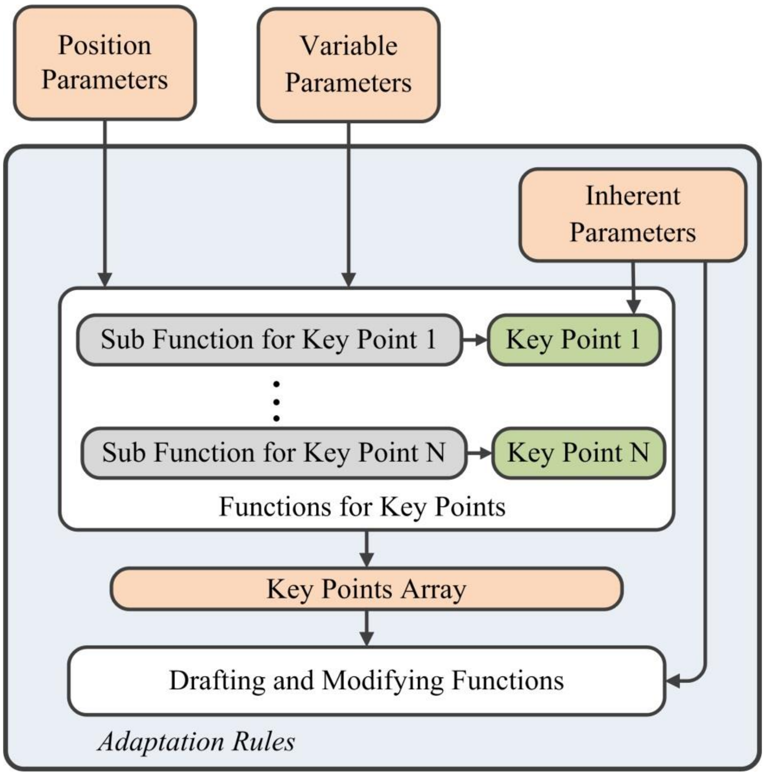


Figure 14 Design elements composing framework

The composing algorithm first decodes the information of the design defined in the three-array data structure (see section 3.2 *style database*), deciding which design elements should be chosen. The algorithm next calculates the relevant position point and variable parameters.

The example skirt sketch shown in Figure 12 is used to illustrate how the design sketch composing engine works. The parametric model of the skirt tells that design elements of yoke (level 2 key design element), panel, slit and pocket (level 3 design elements) are involved in addition to waist and hem elements. The construction of yoke and pocket are explained below.

The decoded parametric model invokes the second level key design element of angle yoke style 1, see Figure 15. In the style database, angle yoke style 1 is defined by a 'Position Parameter' and a 'Variable Parameter', and it is constructed by an adaptation rule - 'Angle yoke style 1' sub-function. The sub-function first corresponds point 'P1' in Figure 15 to 'Point A' in Figure 13, which is known from the inherent parameters of the silhouette curve. With the known silhouette curve, point 'P2' is calculated by 'Position Parameter'. Secondly, points 'P3' and 'P4' are calculated, based on point 'P2' and 'Variable Parameter'. Finally, 'Angle yoke style 1' sub-function constructs the feature by connecting all points with straight lines and curves as a close region.

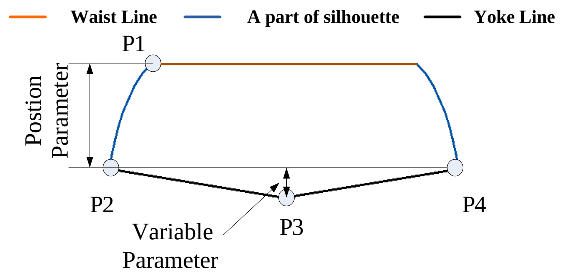


Figure 15 Construction of angle yoke style 1

The decoded parametric model defines that patch pocket style 3 (Figure 16(a)) should be included in the sketch. The patch pocket style 3 is defined as an object block in the style database with 3 parameters 'Pick Point', 'Default Width', 'Default Height', and 'Pocket Angle';

it is constructed by an attachment rule. The attachment rule first calculates the position of ‘Insert Point’ using ‘X Position Parameter’ and ‘Y Position Parameter’ (as shown in Figure 16(b)), which are defined as fractions of half hip-width and of waist-to-hip length. Next, scaling ratios in X and Y direction are calculated from ‘Target Width’, ‘Default Width’ and ‘Target Height’ and ‘Default Height’. Finally, the attachment rule assigns the ‘Pick Point’ of the pocket block to the position of the ‘Insert Point’, at an angle of ‘Pocket Angle’ that defined as the angle between the block width and the horizontal level, and scales the pocket block according to the scaling ratios.

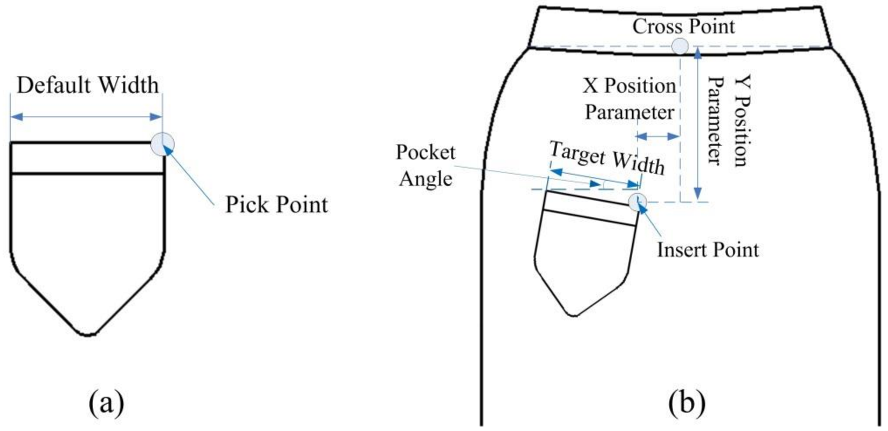


Figure 16 Construction of patch pocket style 3

4. Web-based graphic user interface (GUI)

Unlike transaction-based computer systems (e.g. enterprise resource planning (ERP) systems), where the user interface mainly displays texts (via Web browsers if it is Web-based), the proposed Web-based sketch design system adopts graphical icons and presents results in graphs and figures. The Web-based GUI consists of selection folders, a parameters adjustment panel, an information panel and a set of function buttons, as shown in Figure 17. The *selection folders* contain all parameterised design elements in the style database.

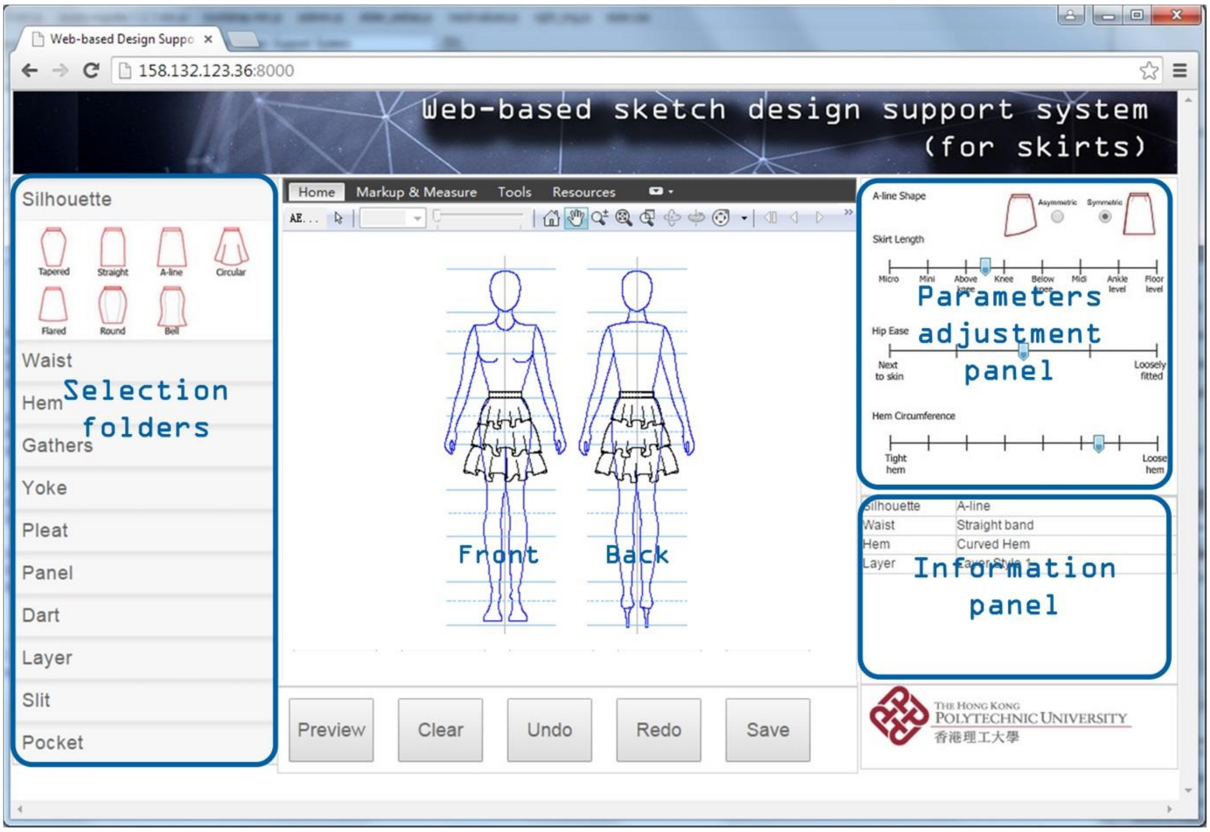


Figure 17 The Web-based GUI design

To allow users perceive and assess the designs, the resulting technical sketches (of both front and back views) are displayed together with the figure templates. The procedures to create a sketch are as follows:

Step 1: Users first choose a kind of silhouette from the *'Silhouette'* folder in the *selection folders region*. Users can adjust the parameters of the selected silhouette in the *parameters adjustment panel*.

Step 2: Users next choose waist type and hem types from the *selection folders*. If users do not specify a hem type, a default hem type will be used to compose the skirt silhouette. Apart from waist and hem, all other types of key style elements (level 2 in Figure 5) and design details (level 3 in Figure 5) in the style database are provided in the *selection folders*. The corresponding parameters for each selected design element are listed in the *parameters adjustment panel* and can be defined by users. The *information panel* shows all selected design elements.

Step 3: Users press the *preview* button to compose and display the resulting sketch in the central region. Users can use the built-in zoom function to check the detail of the resulting sketches. If users want to modify the sketch, user can click the corresponding design element in the *information panel* to invoke relevant parameters to be displayed on the *parameters adjustment panel* for editing. Other functional buttons including *undo* and *redo* are also provided for users to quickly browse previous results. Along the design process, users can stop and press *clear* button to start again at any time or to create a new design. At the end, users can press *save* button to output and download sketches in DXF files. There is an accompanying video showing the operation of this system with this paper.

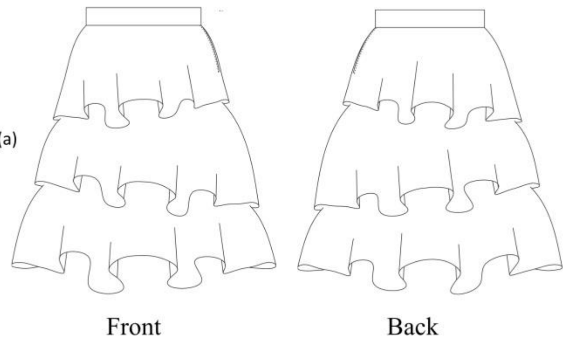
5. Controller

With reference to Figure 3, the controller manages the workflow of the system, bridging between the SRCM and the Web-based GUI. When a user submits a login request, the controller would validate the request through the database management system. If the request is valid, the controller will request the database management system to allocate disk space in the database server for the corresponding users. Next, when the user selects and defines design elements and the parameters via Web-based GUI, the parameters will be backed up in the corresponding disk space and sent to the SRCM through the controller simultaneously. Later, the controller also stores the output sketch file from the SRCM to the disk space and creates a record in the database management system. At the same time, the controller sends the file path of the sketch to the Web-based GUI, which loads the file and renders it to display at client end. User evaluates whether the sketch is satisfactorily created. If the sketch satisfies the user's needs, the corresponding DXF file can be downloaded using the file path recorded in the database management system which would be provided by the controller. Otherwise, users can adjust the selection of design elements and the relevant parameters to render another sketch. Lastly, user can choose to design a new one or exit the system.

6. Results and discussion

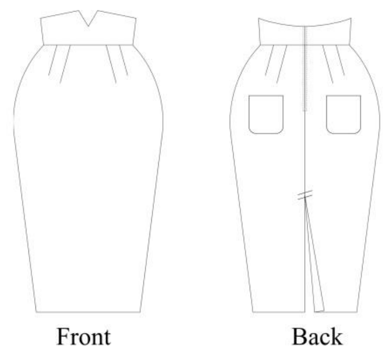
6.1 Resulting sketches

(a)



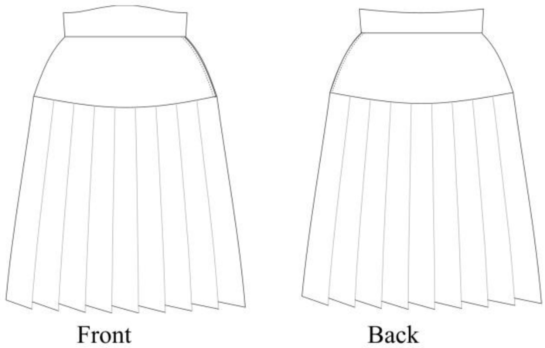
Asymmetric
Silhouette : Flared
Waist: Straight band
Hem: Curved hem
Layer: Layer style 1
Opening: Zip at side

(b)



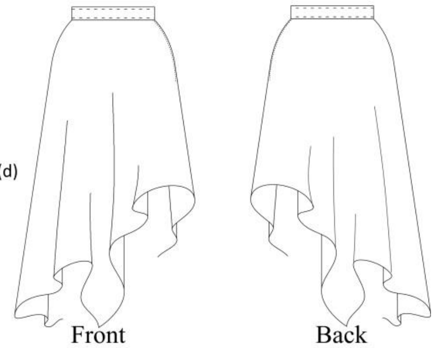
Symmetric
Silhouette :Tapered
Waist: High-waist Cuffs Style 2
Hem: Straight Hem
Dart: Graduating Dart (Descending)
Slit: Straight Slit (Back)
Pocket: Patch Pocket Style 1 (back)
Opening: Zip at CB

(c)



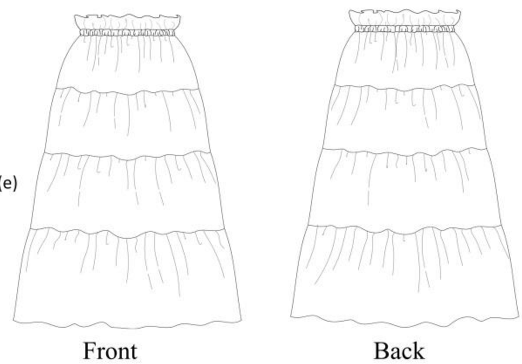
Symmetric
Silhouette : A line
Waist: High-waist Cuffs Style 3
Hem: Curved hem
Yoke: Straight Yoke
Pleat: Knife pleats
Opening: Zip at side

(d)



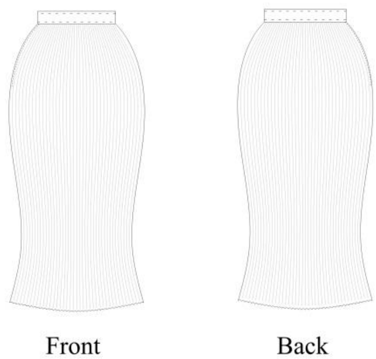
Asymmetric
Silhouette : A line
Waist: Straight band (with stitch)
Hem: Handkerchief hem
Opening: Zip at side

(e)



Symmetric
Silhouette : A line
Waist: Elastic Waist Style 2
Hem: Curved hem
Layer: Layer style 3 (Attached Gathered)
Ascending

(f)



Symmetric
Silhouette : Bell
Waist: Straight band
Hem: Curved Hem
Pleat: Fortuny Pleat
Opening: Zip at side

Figure 18 Some sketch results generated by the system

Figure 18 shows six result skirts designed using the Web-based design support system. Each skirt design contains both front- and back-view sketches, and the selected silhouette and key style elements and design details are also listed in the figure.

Table 4 shows the computation time of the six designs in Figure 18. The computation time includes both the system calculation and drawing time, but excludes the time spent by users on selection and definition of design elements. Information transmission depends on the quality of the network; normally, it takes less than three seconds.

Table 4 Computation time of different designs in Figure 18

Design	(a)	(b)	(c)	(d)	(e)	(f)
Number of curves/lines	66	35	52	38	24+120 blocks	98
Computation time(s)	5.31	1.34	2.12	4.3	5.78	3.23

System configuration: CPU:2.1GHz Intel i7-3612QM, 8GB Ram

6.2 An experimental evaluation

In order to evaluate the effectiveness of the web-based sketch design support system, 30 subjects were invited to evaluate the prototype system. All recruited subjects are either working in the fashion industry or current students studying fashion related programmes in the Institute of Textiles and Clothing of The Hong Kong Polytechnic University or in the Fibre Science and Apparel Design Department of Cornell University. Each recruited subject participated in a face-to-face interview individually. In the interview, each subject was introduced with the prototype system, and then was asked to use the system to create two skirt styles. After which, subjects were asked to rate the system with 5-point scale (strongly disagree, disagree, neutral, agree, and strongly agree) on the seven statements (Table 5). Subjects were also asked at the end of the interview for comments and/or suggestions regarding the prototype system.

Table 5 Statements used to evaluate the system

Number	Statements
(*i*)	This system helps standardise flats with patternmaking in garment manufacturing.
(*ii*)	Standardised flats are easy to understand.
(*iii*)	Standardised flats reduce potential problems caused by varied sketch interpretations among different parties of the product development team.
(*iv*)	This system speeds up the fashion design process.
(*v*)	This system is easy to use. (in comparison with other CAD software)
(*vi*)	This system can inspire you to create more designs.
(*vii*)	I like this system.

The system evaluation results are shown in Table 6. In general, the prototype system received positive comments from the subjects. The majority of the subjects agreed that the prototype system is easy to use (statement (*v*)) and with the aid of the system, it speeds up the fashion development process (statement (*iv*)). These are the main objectives for developing this sketch design support system.

Most subjects agreed that the standardized flats generated from the prototype system are easy to understand (statement (*ii*)) and it can reduce potential problems caused by varied interpretations on flats among different parties of the product development team (statement (*iii*)). With the above reasons, 80 per cent of the respondents agreed that the system can help the standardisation of the flats with patternmaking in garment manufacturing (statement (*i*)). It can indicate the SRCM can generate good sketch results.

Only 36.7 per cent of the respondents agree that the system can inspire them to create more designs (statement (*vi*)). However, this is not the key objective of the proposed system, because the system is not designed to replace designers, but assist users to generate sketches and to improve the overall design efficiency. All in all, the sketch design support system is well received by the majority of the subjects (statement (*vii*)).

Table 6 Survey results of the design support system

Statement	***Mode***	***Median***	***Mean (SD)***	***Range (Spread)***	***Disagree (1-2)***	***Agree (4-5)***
(*i*)	4	4	4.067 (0.69)	3-5	0%	80%
(*ii*)	4	4	3.900 (0.81)	3-5	0%	66%
(*iii*)	4	4	3.767 (0.79)	2-5	3.3%	66%
(*iv*)	4	4	3.900 (0.89)	2-5	6.6%	73.3%
(*v*)	4	4	3.933 (0.89)	3-5	0%	66%
(*vi*)	3	3	3.167 (0.97)	2-5	26.7%	36.7%
(*vii*)	4	4	3.833 (0.66)	2-5	3.3%	70%

Users' feedbacks and comments were collected from subjects in regard to the prototype system. Some positive comments received include *"The concept is very good ... it can help to* *unify the details and avoid misunderstanding between designers and pattern makers*." *"Production drawing is drawn on top of a human figure ... It makes clear the design proportions ... avoid inconsistent proportion estimation between pattern makers and designers, it can help shorten the sample development process.*" Negative comments were also heard that users commented only limited styles can be created. This is because the style database of the prototype system is not comprehensive enough. In the current system, sketches are formulated as unique combinations of different levels of design elements, including silhouette, key style elements and design details in the style database, so the 'creativity' of the system depends on how comprehensive of the style database is. The expansion of the style database is not difficult. Some subjects gave valuable suggestions on the system. For example, it was suggested that a measurement function should be added so that designers can indicate the exact measurements on the designs. Others recommended the addition of rendering tools for adding colour and texture.

Generally speaking, this system has been positively rated by most participants, and they believed the system could be used to create most ready-to-wear styles after some optimisations. Moreover, they commented that the system can in fact be used by general users.

6.3 System advantages and future work

As described in the *Introduction*, the proposed system has four unique characteristics or advantages, namely fully compatible design elements, auto-adaptation for customised human model templates, parameterised and compatible output sketches, and the use of Web technologies. Figure 19 illustrate that the system can generate sketches with ‘fully compatible design elements’. In the first row of the figure, the parameter regarding the number of knife pleats is changed, and the system creates pleats that are compatible with the silhouette defined; in the second row, the number of knife pleats is fixed, the silhouette parameters are altered, the system can generate compatible and balanced pleats automatically; in the third row, the number of layers is altered, all garment details namely the layering and gathers are arranged properly. With the system, users can avoid tedious and time consuming stroke by stroke drawing. It saves a lot of time, in particular for designs involved with many details. In addition, modifying designs and adjusting design details can be completed in a matter of seconds with this system.

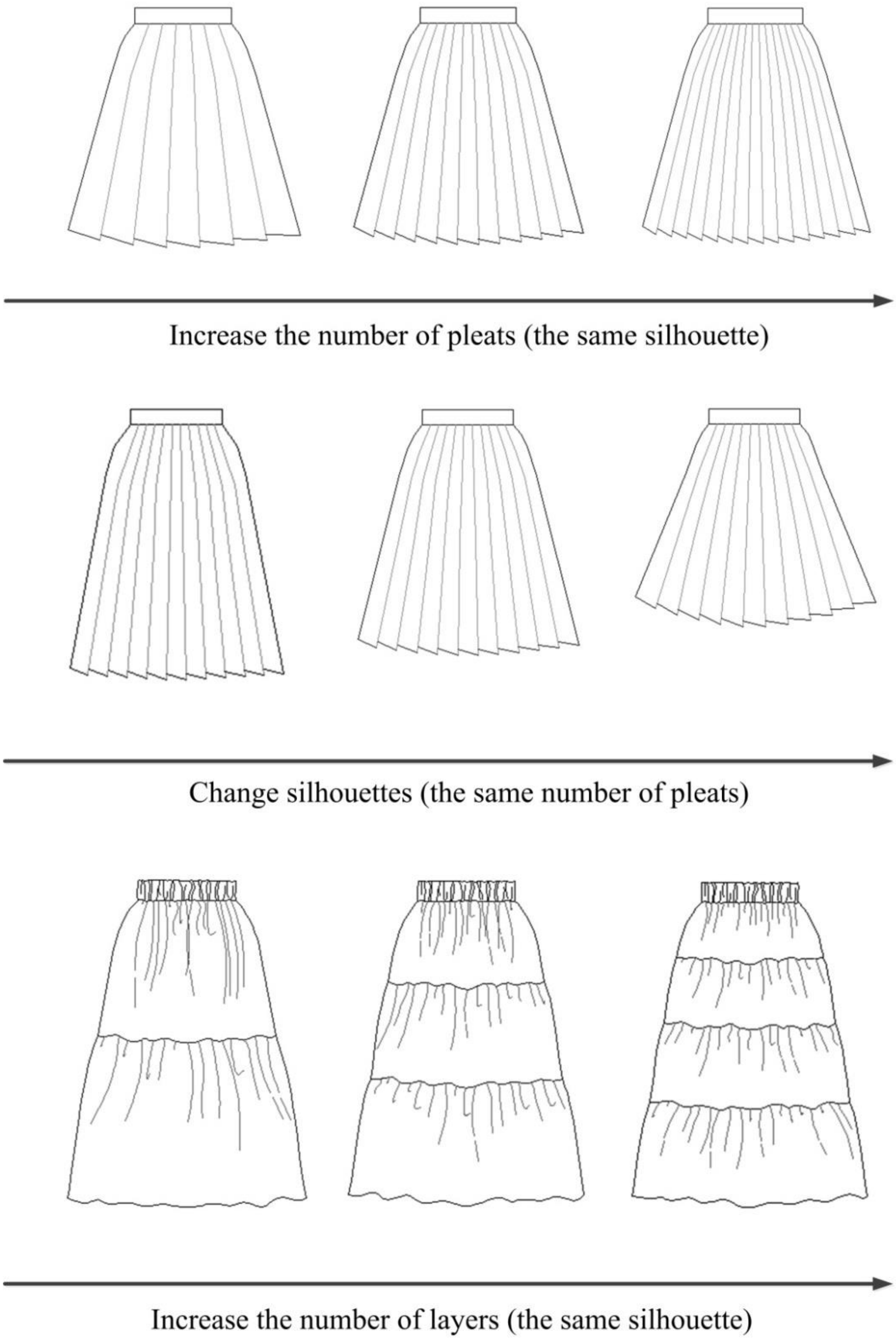


Figure 19 Examples illustrating that design elements are fully compatible

The current system can be easily extended or improved in the following areas. First, the style database can be updated by introducing more design elements. New elements can be easily introduced using object-oriented programming, and an interface will be provided for users to define the object properties. For higher level design elements, design details can be converted as block objects. Any update to the design elements does not influence the operation of other existing elements. The web-based structure of the system provides convenience for the update of the style database, which resides at server-end, and users at the client-side are seldom affected. By continuously updating the style database, the proposed system can be used to design most ready-to-wear styles.

Second, the current system generates technical sketches that include only lines and curves without any texture or colour information. The system can be easily extended to add colour or texture information to the generated technical sketches. Colour filling and texture mapping is easy, because design elements are constructed as closed regions in the system.

Third, the output sketches contain all the explicit design information, for example where darts are placed, the size and length of the darts etc., and such design information are ready to be used in pattern design. Automatic patternmaking and virtual simulation can be integrated in the system in the future. To integrate sketch design with pattern design, it is necessary to confine the generated designs are practical ones. The relationships between design elements have been defined in the parametric models (equations (1) to (8)), yet more studies must be carried out to govern the generation of realistic technical sketches.

Fourth, the system can be extended to smart-phone platform. The current method has tremendously lowered the complexity of sketching to simple drag-and-drop operations, by which a sketch can be created with a few mouse clicks. It can be used by general customers to create their own designs. The use of Web technologies implies the system can be readily implemented on smart phone platform. This can be developed as a tool to understand customer's preferences (Mok et al., 2013).

7. Conclusions

In this paper, a Web-based design support system for technical sketches of fashion products has been developed. The system can handle the drawing process automatically, which is different from traditional stroke by stroke sketching. It allows users to easily and efficiently create flats of ready-to-wear styles. Moreover, the output flats from the system are fully compatible with other commercial CAD systems and contain explicit design information that can reduce variations in design interpretations and make it immediately ready for downstream pattern making. Furthermore, the system is implemented on a Web server, thus users can create designs with any computer connected to the Internet. Web-based technology also encourages collaborative design, and streamline the product development process because users can design anytime anywhere across the world. A prototype system has been evaluated by designers and design students of fashion schools, and it is highly rated by designers who need to work closely with factories in overseas production plants.

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Appendices

Appendix 1: Mathematical definitions of silhouette parameters $\boldsymbol{S} = [S_1 \quad S_2 \ldots S_8]$

$$S_1 = \begin{cases} 0 & \text{asymmetric silhouette} \\ 1 & \text{symmetric silhouette} \end{cases} \tag{A-1}$$

$$S_2 = D(L_{\text{swt}}, L_{\text{hp}}) / d_{\text{wh}} \tag{A-2}$$

where $D(a, b)$ indicates the distance between a and b; L_{swt} is the level of skirt waist; L_{hp} is the hip level; and d_{wh} denotes the distance between waist level and hip level on the human figure template (croquis) (see Figure A-1).

$$S_3 = d_{\mathrm{wh}} / D(L_{\mathrm{hp}}, L_{\mathrm{shm}}) \tag{A-3}$$

where L_{shm} is the hem level of the skirt.

$$S_4 = w_{\mathrm{wt}} / w_{\mathrm{shp}} \tag{A-4}$$

where w_{wt} represents the width of the waist of the given human figure template (see Figure A-1), and w_{shp} indicates the width of the skirt at the hip level.

$$S_5 = w_{\mathrm{shm}} / w_{\mathrm{shp}} \tag{A-5}$$

where w_{shm} is the width of the skirt hem.

$$S_6 = \begin{cases} 0 & \text{default shape - straight silhouette from hip to hem} \\ 1 & \text{silhouette - from hip to hem as a curve} \end{cases} \tag{A-6}$$

$$S_7 = D(L_{\mathrm{hp}}, L_{\mathrm{style}}) / D(L_{\mathrm{hp}}, L_{\mathrm{shm}}) \tag{A-7}$$

In case of curve side seam, an additional style point is used to define the side seam curve (see Figure A-1). L_{style} in Equation (A-7) is the level where the style point locates.

$$S_8 = w_{\mathrm{style}} / w_{\mathrm{sh}} \tag{A-8}$$

where w_{style} denotes the width of the skirt on the style point level along the side seam.

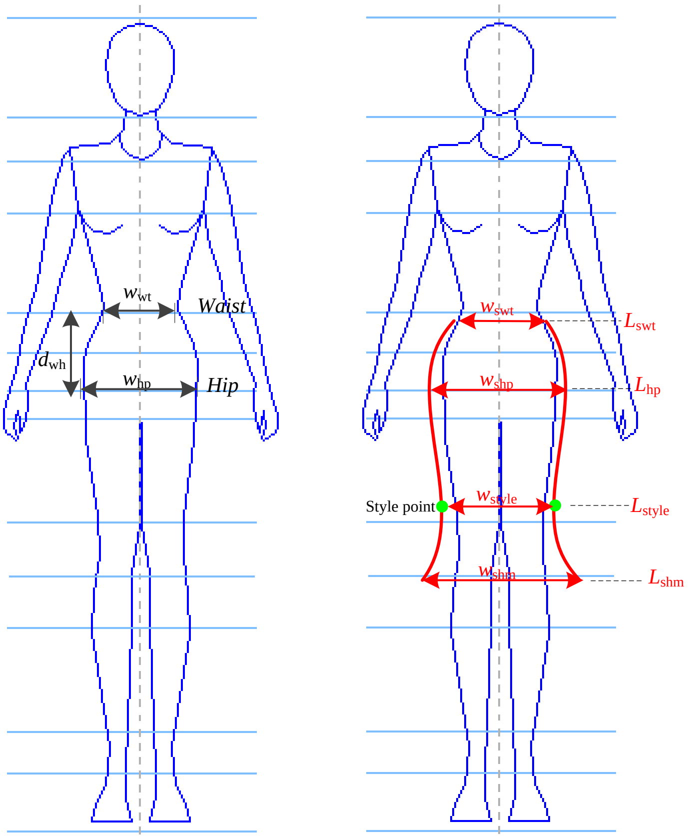


Figure A-1. Human figure template and width and level definition

Appendix 2: Mathematical definitions of shape classifier parameters ***C***= [*C*₁ *C*₂ … *C*₇]

$$C_1 = w_{\max} / D(L_{swt}, L_{shm}) \tag{B-1}$$

where $w_{\max}$ represents the maximum width of the skirt, and $w_{\max}$ = max{ w_{shp} , w_{shm} , w_{style} }. According to equations (A-4), (A-5) and (A-8), $w_{shp} = w_{wt} / S_4$, $w_{style} = w_{shp} / S_8$ and $w_{shm} = w_{shp} \cdot S_5$. $D(L_{swt}, L_{shm}) = S_2 \cdot d_{wh} + d_{wh} / S_3$ is deduced from equations (A-2) and (A-3).

$$C_2 = D_e = w_{shp} - w_{hp} \tag{B-2}$$

$$C_3 = (w_{shp} - w_{wt}) / d_{wh} \tag{B-3}$$

C_3 defines the tangent direction of hip curve (see 'TA1A' in Figure 13). If C_3 > 0.53, the angle between the tangent direction and vertical direction is 30 degree; otherwise, the angle is 45 degree.

$$C_4 = \left(w_{\mathrm{shp}} - w_{\mathrm{swt}}\right) / D\left(L_{\mathrm{swt}}, L_{\mathrm{hp}}\right) \tag{B-4}$$

According to equation (A-2), $D\left(L_{\mathrm{swt}}, L_{\mathrm{hp}}\right) = S_2 \cdot d_{\mathrm{wh}}$.

$$C_5 = \left(w_{\mathrm{shm}} - w_{\mathrm{shp}}\right) / D\left(L_{\mathrm{hp}}, L_{\mathrm{shm}}\right) \tag{B-5}$$

$D\left(L_{\mathrm{swt}}, L_{\mathrm{hp}}\right) = S_2 \cdot d_{\mathrm{wh}} / S_3$ If S_6 = 0, C_5 is used for silhouette classifications as follows

$$C_5 = \begin{cases} [-1, -0.0175) & \text{Tapered} \\ [-0.0175, 0.087) & \text{Straight} \\ [0.087, 0.268) & \text{A - line} \\ [0.268, 0.466) & \text{Flare} \\ [0.466, 1] & \text{Circular} \end{cases}$$

If S_6 = 1, S_8 define silhouette classifications

$$S_8 = \begin{cases} > 1 & \text{Round shape} \\ < 1 & \text{Bell shape} \\ 1 & \text{refers to } C_5 \text{ classifications} \end{cases}$$

If S_6 = 1, C_6 and C_7 are calculated as follows

$$C_6 = \left(w_{\mathrm{style}} - w_{\mathrm{shp}}\right) / D\left(L_{\mathrm{hp}}, L_{\mathrm{style}}\right) \tag{B-6}$$

where $D\left(L_{\mathrm{hp}}, L_{\mathrm{style}}\right) = S_7 \cdot (d_{\mathrm{wh}} / S_3)$.

$$C_7 = \frac{w_{\mathrm{shm}} - w_{\mathrm{style}}}{D\left(L_{\mathrm{hp}}, L_{\mathrm{shm}}\right) - D\left(L_{\mathrm{hp}}, L_{\mathrm{style}}\right)} \tag{B-7}$$

Appendix 3: Explanations of definition equations of design details

Design details were defined as the third level design element, which are defined in equations (4) to (8). The definition of (4) and (5) are used as examples to illustrate the definition.

Equation (4)

$$WaistStyle(W_1, W_2, ...) = f^{(W)}(S_2, DF) \quad \text{(a)}$$

$$WaistStyleDetails(WT_{i1}, WT_{i2}, ...) = f^{(WT)}(W_i) \quad \text{(b)}$$

In equation (4a), W_i indicates the style subgroup of waist, and some examples are listed in Figure 10. Among all waist style subgroups, some are high waist styles and some are low waist styles. Thus, S_2 is used to define waist style and S_2 decides the skirt waist level.

In equation (4b), WT_{ij} represents the *j*-th parameter of W_i. The total number of parameters depends on W_i, but at least contains two parameters for waist position and width.

Equation (5)

$$HemFinishing(HF_1, HF_2, ...) = f^{(HF)}(DF, C_5 / C_7) \quad \text{(a)}$$

$$HemFinishingDetails(HFT_{i1}, HFT_{i2}, ...) = f^{(HFT)}(HF_i) \quad \text{(b)}$$

In equation (5a), HF_i represents the style subgroups of hem, and some examples are listed in Figure 10. For skirts, style subgroups of hem are compatible with only certain silhouette shape. For example, the straight hem (line hem) is suitable for straight skirt but not flare skirt. Therefore, C_5 and C_7 are used in the definition of hem style.

In equation (5b), HFT_{ij} represents the j-th parameter of HF_i. Similar with the waist, the total number of parameters depends on HF_i, but with at least two parameters for hem position and width.

Appendix 4: Explanation of equation (9)

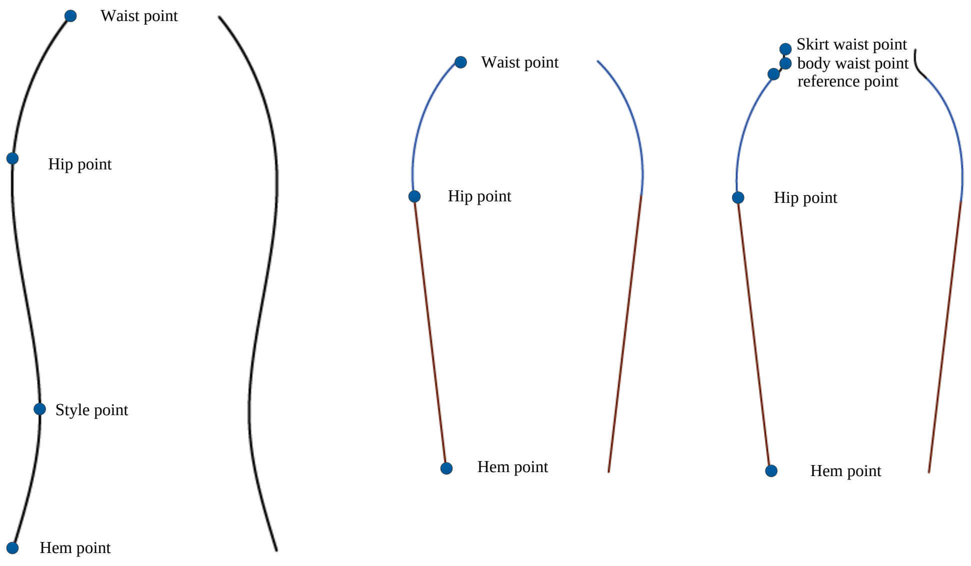
Equation (9)

$$MaxNum = NumFunction(Silhouette(Shape) = f^{(S)}(S_1, S_2, ...S_8))$$

The $NumFunction(\cdot)$ is calculated as follows

$$MaxNum = \begin{cases} 1 & \text{bell/round shape with normal/low waist} \\ 2 & \text{tapered/straight/A - line/flare/circular shape with normal/low waist} \\ 2 & \text{bell/round shape with high waist} \\ 3 & \text{tapered/straight/A - line/flare/circular shape with high waist} \end{cases}$$

Figure D-1 show some examples of silhouette curves with key points.



(a) (b) (c)

Figure D-1. Examples of silhouette curves. (a) bell shape with normal waist (b) tapered shape with normal waist (c) tapered shape with high waist