A STEP TOWARD AN INTELLIGENT AND INTEGRATED COMPUTER-AIDED DESIGN OF APPAREL PRODUCTS

A Thesis Submitted to the College of

Graduate Studies and Research

In Partial Fulfillment of the Requirements

For The Degree of Doctor of Philosophy

In The Division of Biomedical Engineering

University of Saskatchewan

Saskatoon

By

Yu Zhao

PERMISSION TO USE

In presenting this thesis in partial fulfilment of the requirements for a postgraduate degree from the University of Saskatchewan, I agree that the libraries of this university may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis work or, in their absence, by the Head of the Department or the Dean of the College in which my thesis work was done. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission.

It is also understood that due recognition shall be given to me and to the University of Saskatchewan in any scholarly use which may be made of any material in my thesis.

Requests for permission to copy or to make other use of material in this thesis in whole or part should be addressed to:

Head of the Division of Biomedical Engineering
57 Campus Drive
University of Saskatchewan
Saskatoon, Saskatchewan (S7N 5A9)

ABSTRACT

An apparel product (or “apparel”) is a human product. The design of an apparel product (or “apparel design”) should share many features of general product design and be conducted with a high degree of systematics and rationality. However, the current practice of apparel design is relatively more experience-based and ad-hoc than it should be. Besides, computer support to apparel design is quite limited in that there are several software systems available for supporting apparel design but they are isolated.

Two reasons may explain this above situation: (1) absence of the ontology of apparel and apparel design, and (2) absence of a systematic and rational apparel design process. Furthermore, apparel is a specialized type of product in that all three inherent requirements (i.e., function, comfort related to ergonomics, and pleasure related to aesthetics) are equally important, especially the latter, which creates positive affects in the human wearer. In general, knowledge of how to design an apparel product for pleasure/affects is missing from the current design. The general motivation for the research conducted in this thesis is to locate and articulate this “missing knowledge” in order to advance design technology including computer-aided design for modern apparel products.

The specific objectives of the research presented in this thesis are: (1) development of a model for the ontology of apparel or apparel system so that all basic concepts and their relationships related to the apparel system are captured; (2) development of a systematic design process for apparel that captures all the inherent characteristics of design, namely iteration and open-endedness; and (3) development of a computer-aided system for affective design for apparel, whereby human feeling once described can be computed with the result that an apparel product meets the wearer’s “feeling needs” (functional and ergonomic needs are assumed to be satisfied or not the concern of this thesis).

There are several challenges to achieving the foregoing objectives. The first of these is the understanding of ontology for apparel and apparel design, given that there are so many types of apparel and ad-hoc apparel design processes in practice. The second challenge is the generalization and aggregation of the various ad-hoc apparel design processes that exist in practice. Third is the challenge presented by imprecise information and knowledge in the aspect of human’s affect. All three above challenges have been tackled and answered in this thesis.

The first challenge is tackled with the tool of data modeling especially semantic-oriented data modeling. The second challenge is tackled with the general design theory such as general design phase theory, axiomatic design theory, and FCBPSS knowledge architecture (F: function, C: context, B: behavior, P: principle, SS: state and structure). The third challenge is tacked with the data mining technique and subjective rating technique.

Several contributions are made with this thesis. First is the development of a comprehensive ontology model for apparel and apparel design that provides a basis for computer-aided design and manufacturing of apparel in the future. Second is the development of a general apparel design process model that offers a reference model for any specific apparel design process. Third is the provision of new “data mining” technology for acquiring words in human language that express affects. It should be noted that this technology is domain-independent, and thus it is applicable to any other type of product for affective design. The final contribution is the development of a method for searching apparel design parameters which describe an apparel product meeting a wearer’s required feelings described by “feeling words”. The database of words and the algorithm can be readily incorporated into commercial software for computer aided design of apparel products with the new enabler (i.e., design for affect or feeling).

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to my supervisor, Professor W. J. (Chris) Zhang. Throughout my PhD studies, he constantly provided me with research ideas and instructed me in English communication at a professional level. He was very patient in guiding my PhD research for four years. As a good senior friend, he taught me a great deal about living in the Canadian culture.

I would like to thank my co-supervisor, Professor Madan M. Gupta. He was kind and patient in helping me throughout my PhD study.

Many thanks go to other members of my advisory committee, including Professor Daniel Chen, Professor Julita Vassileva, and Professor William Laverty. They provided me with valuable suggestions and ideas that greatly improved my research.

I also would like to express my appreciation to Dr. Wendy Moody in Anglia Ruskin University (ARU) at Cambridge, UK. She provided me with the opportunity to visit ARU and gave me helpful suggestions for my thesis. Thanks also go to Chen Wang for his help in guiding me in use of the data-mining software, and Ki-Young Song for his help in applying artificial neural network techniques in my research.

Many thanks go to my kind roommates Zoe and Esther. They gave me immeasurable encouragement and help during my PhD study. I also wish to thank other friends for providing me with help during these four years. They are Jian Sun, Andy Hu, Jessica Han, Dong He, Amy Zhang, Feng Dai, Haili Lu, Mengya Cai, Jun Di, Xu Wang, Fan Fan, Sisi Zhang, Chunyu Zhou, Ming Zhu, Lina Zhang, Xia Wu, Fu You, Yan Yan, Benjamin Klassen, Marybelle, Cara, Nadine, Penny, Jiang Han, Zheng Liu, Dan Zhou and Lan Chen. I would also like to thank my friends in my church community: Rob Arthur, Edith Arthur, Cecilia, Elise, Cam, Joey, Gerrit, and Betty.

I would like to acknowledge the financial support received from the China Scholarship Council for my study during this period of time.

Last but not least, I want to express my deepest gratitude to my family in China. My father Yingguang Zhao and my mother Guanghua Jiang have been both mentally and financially supporting me over these four years. Without them, I doubt that I would have completed my PhD study. Heartfelt thanks go to my other family members, including my aunts, my uncles and my cousins, for their ongoing encouragement.

This thesis is dedicated to

My father, Yingguang Zhao

My mother, Guanghua Jiang

My aunt, Yingxiao Zhao

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AAL	affective adjectives list
ADPs	apparel design parameters
ADP-TO-AW	apparel design parameter to affective word
ARTEXDGS	ARTEX design & grading system
ADT	axiomatic design theory
AW	affective word
BP	backpropagation
CAD	computer-aided design
CADOA	computer aided-design of apparel
C2CAD	cradle to cradle apparel design
DF	document frequency
DFF	design for affect
DP	design parameter
FCBPSS	function-context-behavior-principle-states-structure
F-E-A	function, expressive and aesthetic
FEA	function, ergonomic and aesthetic
FEA-R	function, expressive and aesthetic-requirement
FRs	functional requirements
FW	feeling word
AW-TO-ADP	affective word to apparel design parameter
GWR	general word reference
HOSO	higher-order synaptic operation
HSL	hue-saturation-lightness
HSV	hue-saturation-value
HTS	hyperbolic tangent sigmoid
ICT	information and computing technology
ID	identity
IDF	inverse document frequency
I-ICT	internet-based information and computing technology
KE	Kansei Engineering
LF	purlin function
LR	logistic regression

LS	log sigmoid
LSO	linear synaptic operation
LM	levenberg-marquardt
MD	marvelous designer
MIMO	multiple-input and multiple-output
MSE	mean squared error
NEOFFI	neuroticism, extroversion, openness, agreeableness and conscientiousness
NNs	neural networks
OKP	one-of-a-kind production
PANAS	positive and negative mood affect scale
QSO	quadratic synaptic operation
R	regression coefficient
RGB	red-green-blue
SADP	systematic apparel design process
SPSS	statistical package for the social sciences
TF	term frequency
TF-IDF	term frequency-inverse document frequency
UML	unified modeling language
2D	two-dimension
3D	three-dimension

CHAPTER 1 INTRODUCTION

1.1 Background and motivation

Apparel is essential to human beings, originally emerging as a necessity for survival in harsh environments. As human history has moved forward including evolution of society and advancement of technology, apparel products no longer are produced solely for purposes of survival. Apparel today is a product that is expected to be conducive to a healthy and comfortable state with the human body and also to positively influence the human mind (both cognition and emotion). Globally, fashion shows occupy an important role in the entertainment lives of many people. The current trend in response to humans' need for apparel products is that the products are required to be functional, comfortable, and affective, as well as available in a short delivery time and at low cost.

An ideal scenario for acquisition of new apparel would be that a customer requests an apparel product by specifying the desired requirements from his or her home, and then within several hours the requested product arrives at the customer's home or at some other specified destination. This as-yet-visionary scenario would require the availability of a computer system that could perform apparel design and availability of a manufacturing system that could fabricate an apparel product based on the resulting design specification.

The challenges in meeting the aforementioned needs are numerous, and addressing them is the motivation of this thesis. Unarguably, modern computing and information technology will play a role in addressing these challenges. In the recent decade, several computer-aided design (CAD) systems have been developed (including Marvelous Designer, Fashion Design CAD, and Optitex, to name just three) that have played a role in speeding up the design of apparel products (thus reducing the apparel production/delivery time) and in increasing communications regarding apparel products between customer and designer through the Web system (thus reducing cost for both design and manufacturing).

However, these CAD systems are not integrated with each other and their total intelligent behavior is not high. Another shortcoming with the current state of computer-aided design of apparel (CADOA) technology is that the designer's intention, design rationale, and design management information are not represented in the computer system. A further weakness is that there is no computer support for the affective design of apparel products. The current production practice of the apparel business follows either of the two patterns: (1) apparel manufacturers mass-produce apparel to stock and display in shops, where customers visit to select and purchase the pre-made items, and; (2) customers visit apparel tailors or manufacturers who make customized items. Currently, the fashion business community is largely isolated from the above two patterns, in that the designers work manually to create their work which is artistic in nature.

Consequently, several questions emerge regarding how to reduce the gap separating the current state of apparel design and manufacturing technology from a more desirable apparel business.

Question 1: How could various CADOA programs be integrated to work as a whole so as to improve the overall intelligence of CADOA?

Question 2: How could the communication between the CADOA programs (and design experts) and the customers be improved so as to human intelligence and computer intelligence can all be exploited in design?

Question 3: What could be a more systematic and rational design process that captures the nature of a design process (open-endedness and iteration)?

Question 4: How could a computer program system "read" the human affect in the context of apparel and "create" an apparel product that meet those specifications?

1.2 Objectives

My thesis research was structured to develop answers to the aforementioned questions. A preliminary investigation led me believe that an ontology or a conceptual model is needed in order to generate answers to the first two questions, and that such a model currently does not exist in the literature. Regarding the third question, I was convinced of the need for a more systematic apparel design process such that the process may be readily computer-automated. Regarding the fourth question, my idea was to computerize the human affect and its relation with the design parameter for apparel products. It should be noted that the design parameter can be derived from the conceptual model, which further implies the importance of a conceptual model for apparel and apparel design. Based on the foregoing deliberations, this thesis defined the following specific research objectives.

Objective 1: To develop a conceptual model (or domain model or ontology model) for apparel products such that the basic notions behind the domain of apparel are captured and defined to facilitate the integration of various design "experts," including computer-based expert systems or agents. The conceptual model as developed should demonstrate its promise in the integration of various CAODA systems as well as in the interface with customers as mentioned before (i.e., Question 1 and Question 2).

The model to be developed is expected to capture the concepts and their relationships inherent to apparel products. The model is generic and template-like, which means that it is applicable to different types of apparel (nursing scrubs, banquet gowns, and athletic uniforms) and a set of data templates with which a model of a particular apparel product under design is created with the templates. Another important purpose of a conceptual model behind the domain of an application (apparel in this case) is that it can provide a "knowledge dictionary" in order to bridge various experts involved in the application domain (Wang et al., 2013); for instance, the domain model of apparel can be converted into computer language by experts and be further developed into computer-aided systems to assist in apparel design, or the domain model could be linked to the vocabulary of the customer for discussion about the apparel between the customer and designer. It is noted that this ontology model is restricted to the apparel structure.

Objective 2: To develop a systematic and rational design process for apparel products. "Systematic" indicates development by a step-by-step procedure, while "rational" means that objectivity in decision-making is preserved (Pahl et al., 2007). The apparel design process should capture open-endedness and iteration, which are two inherent characteristics of a design process. The benefit of such a design process is to promote creativity in design. The current design process for apparel is not able to capture the aforementioned characteristics. Further, the model may also be conducive to capturing management information for support of the design process management.

Objective 3: To develop a database of vocabularies in the context of apparel and apparel design that enables a customer's affective responses to be expressed and to develop their relationship with the apparel design parameters that enables to determine suitable design parameters of an apparel product which may exhibit the customer's affective responses.

It should be noted that unlike customer response to many other industry/consumer products (e.g. machine product), the affective response to apparel products is highly important. In apparel products, the affective need occupies a high proportion of the total need (the other two needs are functional and ergonomic). Design parameters in the apparel design domain represent the structure of an apparel product under design including factors of color, silhouette, and material. It is noted that this thesis does not concern design for function and comfort, and as such, their dependency on affects is ignored.

1.3 Organization of the thesis

Chapter 2 is a comprehensive review of the past and current apparel design and knowledge related to apparel in order to demonstrate relevancy and need for the foregoing research questions and objectives. Chapter 3 presents the development of a conceptual model for apparel products along with some justification for the usefulness of the model. The research content of this chapter is intended to fulfill Objective 1. Chapter 4 offers the development of the systematic and rational apparel design process along with an illustration of this process, and its research content is intended to fulfill Objective 2. Chapter 5 presents the development of a new method for compilation of a set of vocabularies to represent human's affect or emotion in the domain of apparel, and its contents will partially fulfill Objective 3. Chapter 6 puts forward the development of the relationship between the vocabularies discussed in Chapter 5 and the apparel design parameters, and thereby will complete along with Chapter 4 fulfillment of Objective 3. Chapter 7 presents a case study in order to further demonstrate the usefulness of the research outcome stemming from this thesis. Chapter 8 presents the conclusions, as well as indications for some important future work.

CHAPTER 2 BACKGROUND AND LITERATURE REVIEW

The goal of this chapter is to provide a detailed literature analysis in order to give justification for the need of the proposed research. First, some necessary background is presented in the form of definitions of basic concepts in apparel design and manufacturing (Section 2.1). This background also serves to develop the ontology model for apparel (RE: to Objective 1). Section 2.2 presents a critical review of the apparel design process as presented in the current literature. This review will further justify the need for the proposed research, relative to Objective 2 in particular. Section 2.3 presents the Kansei Engineering method, which is a popular approach to affective design. Section 2.4 reviews the data-mining technology and its application to affective design. Therefore, Sections 2.3 and 2.4 together provide further justification for the need of the proposed research, relative to Objective 3 in particular. Finally, Section 2.5 concludes this chapter by making a conclusive statement of the need for the proposed research.

2.1 Concept

Clarification of some of the basic concepts underlying my research may be helpful in facilitating the reading. These concepts and their definitions are as follows.

Definition 2.1. **Apparel** is a general name used for varying sorts of clothing (e.g., skirts, costumes, uniforms, trousers, etc.).

Definition 2.2. **Apparel design** refers to a set of entire activities to develop a specification for apparel that does not exist but is intended to be made – i.e., a mapping process from the requirement to the ultimate structure of the apparel. The structure is as a set of parameters with their relationships that represent information regarding the geometry and the material of the apparel. The parameters are also called design parameters in the context that an apparel product is under design.

Definition 2.3. **Silhouette** is the outline or general shape of an object (Dictionary, 2013a).

Definition 2.4. **Requirement** describes the three aspects of customer need with regard to apparel: functional, ergonomic, and aesthetic.

Definition 2.5. **Functional requirement** is divided into two aspects. One is basic utility for human activity, such as mobility of body, camouflage of body, thermal storage and release through apparel (Dunne, 2004); the other is extra utility, such as radiation protection for apparel designed for outer space activity or flame fire-proofing for firefighter apparel. Note that for the purposes of this thesis, functional requirement refers to the second aspect.

Definition 2.6. **Ergonomic requirement** refers to how easily the function of a product or a system in its interactions and/or involvements with the human, is performed from the point of view of the customer.

Definition 2.7. **Aesthetic requirement** refers to the psychological need of the customer; that is, the arousing of feelings or emotions in the customer when he or she interacts with a piece of apparel (i.e., viewing or wearing an article of apparel).

Definition 2.8. **Affect** is associated with emotion. Emotion is a psychological state that arises spontaneously and unconsciously (Dictionary, 2015a) and is chiefly about a process, while affect is more about the state of an emotional process. In this thesis, term "emotion" and "affect" are used interchangeably.

Definition 2.9. **Green material** is material such that the use of it will not create any harmful effects to the environment and the provision of it will be sustainable in the present process as well as in further and other processes (Dictionary, 2015b). The terms "green material" and "sustainable material" are used interchangeably in this thesis.

Definition 2.10. **Kansei** is a Japanese word for describing human feeling, and was created by a Japanese researcher in the field of engineering aesthetics. In this thesis, the terms "Kansei words" and "affective words" are used interchangeably.

Definition 2.11. **Data mining** is a computational process used to discover patterns of data within a large set of data that represents the information and knowledge within a particular context (Chakrabarti et al., 2006). This process also comprises a feature of learning, since the information and knowledge arise from the existing data. Since this learning process is done by the computer (which is a kind of machine, i.e., computing machinery), learning accrued via data mining is also called machine learning. Methods for machine learning are essential methods of classification and clustering enhanced with statistics. So-called Neural Networks (NNs) is a technique used for classification and clustering capable of development into a method for data mining. If the data or database resides in the Web, data mining is also called web mining (Wang, 2008). In this thesis, the term data mining and web mining are used interchangeably.

Definition 2.12. **Computer-aided design (CAD)** refers to employing computing and information technology to assist in the creation, modification, analysis, and/or synthesis of a design (Sarcar et al., 2008).

Definition 2.13. **Mass customization** refers to a paradigm of product development. If the product development follows a mass customization paradigm, it must exhibit behavior indicating that a large number of customers are satisfied with the manufacturer's provision of the products (i.e., that the products meet individual customers' needs).

Definition 2.14. **Mass personalization** is an offshoot of mass customization in that the products are individually different, i.e., the apparel for one individual is different from that for another individual. Mass personalization is a kind of mass customization yet with an emphasis on the method of satisfying individual differences of the customer; mass customization emphasizes the end of manufacturing – i.e., the result that a large number of customers are satisfied by manufacturing, achieved by capturing the common needs of customers. Mass personalization differs from the current apparel business made-to-stock paradigm, as well as from the tailored "custom-made" paradigm.

Definition 2.15. **Ease** refers to the margin of space between the human body and apparel. It comprises two kinds: wearing ease and design ease. Wearing ease allows for a body's movement, while design ease is the refinements that enhance functionality, ergonomics and/or aesthetics in a 2D (two-dimension) pattern (Figure 2.1).

Definition 2.16. **Block** is the basic fitting template that closely fits the body without the ease added. The template is made with cardboard shapes that represent the human body. The block gives a baseline to the pattern; that is, the pattern is based on the block with geometrical features added (e.g. the ease). The block is of two types: bodice and skirt (Figure 2.2). The bodice block covers the upper part of the body from the shoulder down to and including the waist (Figure

2.2(a)), while the skirt block covers the waist and hip areas (Figure 2.2(b)). The bodice block has an interface for the development of a sleeve pattern (Figure 2.2(a)) while the skirt block has an interface for the development of a trouser pattern (Figure 2.2(b)).

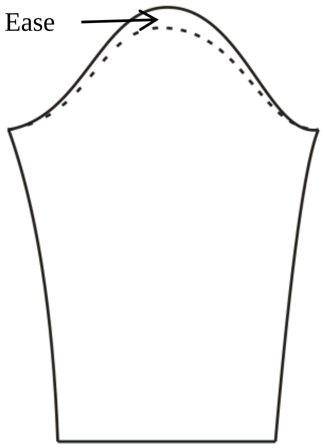
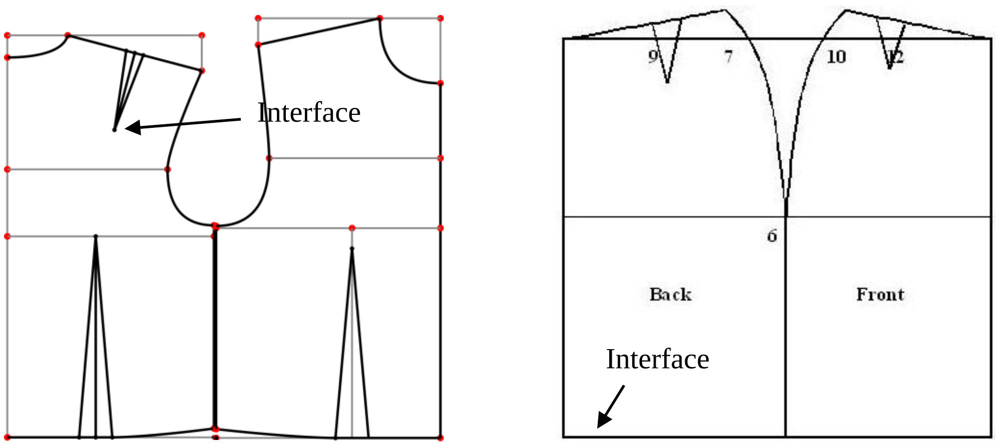


Figure 2.1 Ease

Definition 2.17. **Pattern** is the set of flat 2D (two-dimension) pieces of paper or cardboard and with the ease added on blocks. The material is cut into pieces based on the pattern, and then the 2D material pieces are assembled into 3D (three-dimension) apparel. Figure 2.3 is an example of patterns. Note that there are numerous generic blocks, e.g., upper front block and upper back block, and patterns of different types of apparel (e.g., skirt, jacket, etc.) are specified from the generic blocks.



(a) (b)

Figure 2.2 Blocks: (a) bodice block; (b) skirt block (http://www.sew-brilliant.org/2010/08/20/front-bodice-block-done/. Retrieved June 25, 2014; http://wikieducator.org/Handout_for_drafting_skirt_block/Handout. Retrieved June 25, 2014)

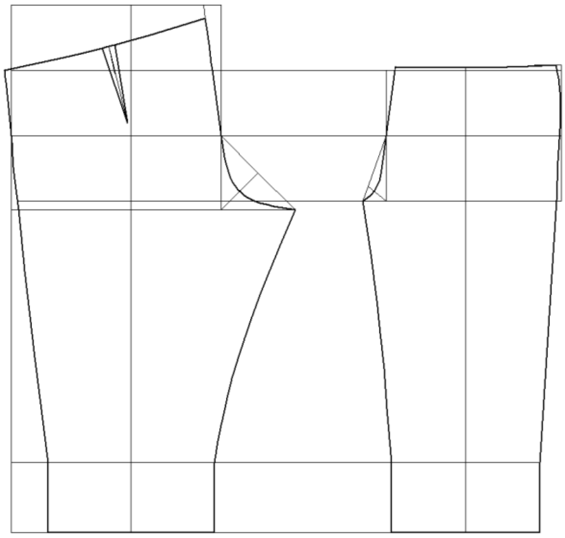


Figure 2.3 Examples of the patterns for pants (left: front; right: back)

Definition 2.18. **Dart** refers to a tapered seam that enables the material to form a three-dimensional shape (Dictionary, 2013b) (Figure 2.4).

Definition 2.19. **Gather** is the feature of apparel resulting from decreasing the length of one piece of material in order to attach it to a shorter piece of material (Figure 2.5).

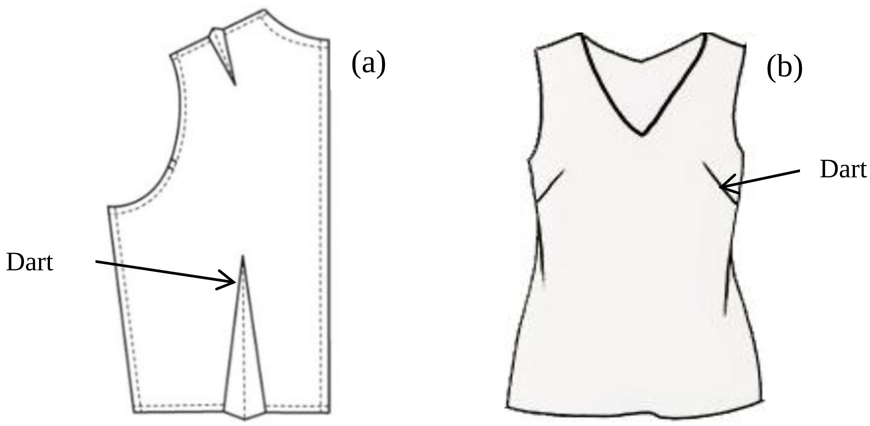


Figure 2.4 (a) Dart on the 2D pattern; (b) dart on the 3D apparel

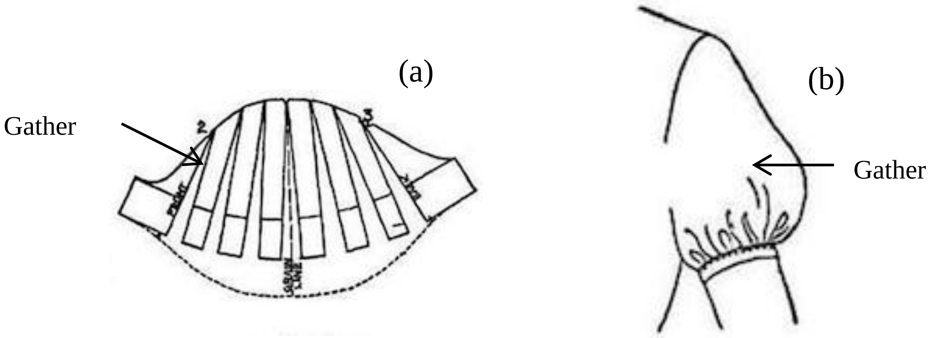


Figure 2.5 (a) Gather on the 2D pattern; (b) gather on the 3D apparel

2.2 Apparel design process

2.1.1 Traditional apparel design process

Apparel and thus apparel design emerged with the realization that the human body needed to be covered for protection from the harmful and damaging effects of harsh climates and environments. One of the earliest evidences of apparel dates back to the Neanderthal (Borrett, 2008). At that time, apparel was made from feathers or skin taken from raptors (birds of prey). There is little sense that apparel design had a distinct identity in the entire process of apparel making; design was simply a part of the process of making. The process was to use sinews and a bone needle to assemble pieces of the animal skin or feather (Borrett, 2008). When man-made fibers evolved for use as the material for apparel, the assembly process remained to be based on sinews and a bone needle. Earliest apparel was worn primarily for its functional effects, with little or no requirement to ergonomic and aesthetic qualities.

Refinements both to apparel design and to the fabrics used evolved concurrent to the evolution of human civilization and the advancement of technology. Eventually, the making of apparel became a specialized occupation and the notion of designing apparel arose. The methods for piecing or assembling pieces of materials (some now fiber-based in addition to the original animal skins) became more sophisticated with the invention of metal-based needles and soft threads. The notion of sewing appeared. A distinct occupation emerged for a person having the specialized knowledge of and technical ability for the skills required for cutting material and assembling/sewing it into apparel. That person was called a tailor. The tailor oversaw all decisions related to design, and manually performed all actions involving the making of apparel.

Emergence of the tailor resulted in several changes in the process of apparel making. First, the activity of design and that of making became slightly separated. Second, the apparel design and making activity became highly customized (Daanen & Hong, 2008), providing an example of OKP (one-of-a-kind production) manufacturing approach. Third, the three aspects of the requirements for apparel (functional, ergonomic, and aesthetic) were considered individually by the tailor according to each separate customer. However, despite these significant advances and in light of our current culture, such tailor-based apparel design and making can be seen as empirical, inefficient, and ad-hoc.

2.2.2 **Modern apparel design process**

Basic concept

Emergence of the modern apparel design process was driven by two forces: (1) the advancement of information and computing technology (ICT) and (2) humans' wish for apparel with greater comfort and functionality, greater positive affect, more variety and creativity in style, lower cost, shorter delivery time, and general sustainability.

Modern apparel product design process is concerned with the following features: (1) iteration, (2) open-endedness, (3) rationality, and (4) systematics. **Iteration** means that design activities can be repeated, and most of the time there is essentially no way to have a straight path in the process from the requirement of a product to the completed design description of the product. **Open-endedness** means that design solutions are multiple at the beginning as well as during the design progressing, and that the best design solutions are arrived at through elaborations and within the context of the whole design. **Rationality** implies that each decision affecting the design issue is made or exists based on reason. **Systematics** means that the apparel product design process can be planned, scheduled, coordinated, and controlled.

Because modern apparel product design process is highly complex, it is essential that the management of it should make sense to apparel designers. Management of modern apparel product design process must meet the following features. Management of modern apparel product process should be conducted in a human-computer collaborative manner to varying degrees, depending on the design environment and on the resources available. The process can be further classified into general design process and specific design process. General process is applicable to all types of apparel, while specific process is applicable only to a specific type of apparel.

While an active role still exists for tailors in apparel production, the modern apparel enterprise departs from that era in that it follows so-called mass production of apparel (just like mass production of cars and most other consumer goods) by taking advantage of rapidly developed and developing machinery and automation technology. This mass production concept has changed the way humans obtain apparel in that when they need apparel, rather than making it for themselves or having it tailor-made for them, they simply go to one of many apparel stores or go online and visit various apparel e-shops to select and buy ready-made apparel. Further, the mass production concept has made the design, the production, and the manufacturing of apparel three completely separate entities. Mainstream modern apparel enterprise is no longer follows the OKP concept of the traditional apparel enterprise. In the following discussion, apparel design, rather than apparel production or manufacturing, will be focused.

General apparel design process

Labat and Sokolowski (1999) proposed a three-phase process for both textile product design and apparel design as follows: (1) problem definition and research, (2) creative exploration, and (3) implementation. At each phase, the steps for proceeding with the design are dependent on the types of apparel and design issues. This general apparel design process is applicable to any type of apparel product. However, the key factors of how to define the problem and how to be creative in solving the problem in the context of apparel are absent in the aforementioned general apparel design process. Besides, the features of any design process, namely open-endedness and iteration, are not addressed. Others have offered proposals of varying phase lengths for the process of apparel design/apparel production, as follows: six phases (May-Plumlee & Little, 1998), eight phases (Burns & Bryant, 2002) and ten phases (Jackson & Shaw, 2006). Following are comments on the design aspects of these integrated design and manufacturing process models.

The design process proposed in both May-Plumlee & Little (1998) and Burns & Bryant (2002) includes concept development, design development, and style selection. The valuable point in their models is the recognition of the importance of development at the conceptual level (which is an important concept in general product design or development). However, style selection was viewed as out of the scope of the concept development in their models, which is a point of some debate. Note that in our study (Zhao et al., 2015), style selection is a part of the conceptual design. One of the valuable features in the design part of the integrated design and manufacturing models by Jackson and Shaw (2006), Carr and Pomeroy (1992), and Gaskill (1992) is that the factor of customer requirement has been taken care by marketing research and development. However, in the aformentioned sutides, individualization or personalization of customers was not considered at all, an absence that gives rise to significant implications. The first is that modern apparel enterprise is still based on the mass production approach. The second is that the psychological aspect of apparel, i.e., affect of the wearer, is not of concern in design. This second implication will be disucssed in detail below.

In the literature mentioned above, apparel design did not involve the requirement of affect with the customer when wearing a particular piece of apparel; for example, that wearing the apparel made the customer feel graceful, beautiful, and/or positive. In fact, only a few studies in the literature acknowledge the relevance to design of affect or emotion or feeling (note that this thesis considers the three words to be interchangeable).

Lamb and Kallal (1992) proposed a model called F-E-A (function, expressive and aesthetic). In this model, they restrict the notion of aesthetics to pretty and beautiful affects only, while the notion of “expressive” refers to the psychological senses in the mind of the customer or wearer when she/he wears the apparel. Bye and Hakala (2005) applied the F-E-A model to design sailing apparel for women. Two aspects of the FEA model warrant debate. First, separation of the expressive and aesthetics may not be possible, as the aesthetic element and expressive element may be coupled, i.e., they may be in conflict with each other. The F-E-A model fails to address this issue. Second, design process based on the F-E-A model is not rational, e.g., there is no scientific elaboration on the words selected to express psychological affects or feelings.

Specific apparel design process

(1) Functional apparel design process

Functional apparel particularly refers to special apparel not commonly worn by most people in daily life. Examples could be the different apparel worn in hospitals or medical clinics by patients, nurses, and doctors. Functional apparel design is unique unto itself because there is a need for special knowledge of design in order to meet specific functional requirements. For instance, the color of the apparel worn by hospital cleaning and maintenance personnel is yet another color (often yellow) distinct from that of the medical personnel.

Gupta (2011) proposed a flow chart for functional apparel design and manufacture. It contains user survey, user requirements, garment design, garment assembly, testing and analysis, and production. That design process clearly is the same as the design process applied to production of general products. McCann et al. (2005) proposed a framework that includes consideration of the aesthetics and culture of the wearer. While this latter is a milestone work in the area of functional apparel design and development, the framework is qualitative and provides no guidelines for how to apply it to the production of functional apparel products.

(2) Costume design process

Costume refers to the apparel worn for a particular occasion (Dictionary, 2015c). Because it is distinct from wear for everyday or social occasions, a costume product is expected to fulfill certain distinct functions and sometimes unusual functions. For instance, a costume product for an actor in a dramatic or theatrical production is expected to fulfill the function of enhancing a character's position and orientation in a highly specific 3D space (Nance, 2009). Therefore, design for costume is more complex than that required both for other types of apparel and also for non-apparel products.

Ingham and Covey (1992) proposed a costume design process comprising four stages, namely planning, finding (pulling, renting), shopping (buying), and recording. In the planning stage, the costume designer develops the requirement for the costume product based on information in the script and through communication with play personnel including the director and the stage designer. The finding (pulling, renting) stage requires a costume product to be prepared through borrowing or renting the apparel then reworking (including redesigning and remaking) it as necessary. In the shopping stage, the designer purchases any materials needed for completion of the costume. Finally, at the recording stage, a description of each costume for each character and the method followed for its construction are recorded. Ingham and Covey's costume design process thereby expresses the costume's characteristics. It is clear that their proposed process actually is a kind of redesign process, one that is alien to the design process of the other types of apparel.

(3) Design for "green" purposes and sustainability

Gam et al. (2009) proposed a so-called C2CAD (cradle-to-cradle apparel design) model for sustainable apparel design and production. The C2CAD model comprises four main steps: (1) problem definition and research; (2) sample making; (3) solution development and collaboration; and (4) production. In the first stage, the user's needs such as functionality, aesthetics, and economy are clarified, and then a design idea for the style of the apparel is generated. The sample-making stage includes material selection, allocation of cost, and design evaluation. At this stage, the so-called green materials are chosen (see Section 2.1 for definition of green material). In the solution development and collaboration stage, the apparel designer and manufacturer work together to conclude the final design and to phase out any non-green materials. The subsequent production stage is quite straightforward.

In the C2CAD framework, the so-called design strongly concerns the selection of materials (i.e., green materials). However, the possibility exists that the green material may conflict with other requirements of the apparel, and how this conflict may be resolved is not addressed in the C2CAD framework. Ultimately, the chief focus for this framework is the green material selection, but in my view the isolation of this activity from the other design contexts is a limitation of C2CAD.

2.2.3 Discussion and concluding remarks

It can be concluded that the current literature on apparel design process contains limitations. First, for each design phase as proposed in the literature, there exists no detailed guideline regarding task at each phase and ultimate goal. This makes the process difficult for the designer to follow and consequently, successful application of the design process models as presented in the literature is in doubt. Second, the division of design phases lacks rationality. In fact, within the entire process of apparel development, design is paid the least attention; most of the process models as discussed above appear to use a sketch or a description to indicate design. The literature appears to suggest that design is not an important element in the apparel development; rather than it is the business of the tailor. It can thus be concluded that the modern ICT seems to be of little use in apparel development. This implies, then, that there is considerable capacity for improvement of the current apparel design and manufacturing process by application of the modern ICT, especially in the area of aesthetics in fashion design (Lin & Zhang, 2006). (Note that “fashion” refers to apparel that captures the current trend of people in our society.) Third, there exists no work on apparel design process management in the literature. This absence may be related to weak understanding of the design process – i.e., the current literature remains rooted in the age of tailor-based design. This could explain why the current literature fails to recognize any need for design process management.

Indeed, design process management makes sense in situations where the design activities involve many steps and steps that may go “back and forth” (Zhang et al., 2011). In the case of modern apparel design, the need for process management depends on the apparel manufacturing paradigm and the demands of the customer. Today, in some areas of apparel design, the apparel-manufacturing paradigm is meshed with the mass customization and mass personalization paradigm, and another trend is that the demand from the customer regarding the aspects of affect, emotion, and/or feeling is increasing greatly (Moody, 2010). Therefore, the apparel design process has become much more complex than ever before, exhibiting with the features of open-endedness and iteration.

In conclusion, the current literature does not provide a design process model that meets the demand of the customer and of the apparel manufacturing industry within the current situation and trend, where in the apparel manufacturing industry meshes with the manufacturing paradigm of mass personalization that particularly highlights the aesthetic aspect of apparel.

2.3 Kansei engineering and its application

2.3.1 Kansei Engineering

Kansei Engineering (KE) is defined as "translating the technology of a customer's feeling about the product to the design elements" (Nagamachi, 1995; Nagamachi et al., 2006). In Kansei Engineering, over 600 words have been developed to represent humans' feelings, and these words are called Kansei words (Nagamachi, 1995). The methods used for developing Kansei words includes: (1) dialogues with salesmen; (2) conversations with customers; (3) extracting words from magazines and books; and (4) gleaning information from experts' experience (Nagamachi, 1995; Nagamachi et al., 2006; Schütte et al., 2004). The details of the methods used for compiling the Kansei words will be discussed in Section 2.4 of this thesis.

2.3.2 Application of Kansei Engineering

Currently, Kansei Engineering (KE) is a very common tool used for representation of humans' feelings and has been applied in a wide variety of industries (Zhao et al., 2015). According to Nagamachi's work (2002), these industries include automotive, construction machines, electrical home appliances, office machines, house construction, cosmetics, and apparel.

In the automotive industry, Kansei Engineering was employed to evaluate the vehicle interior image, including the roominess aspects of the environment of the vehicle cabin (Tanoue et al., 1997). In that study, four Kansei words including "roomy," "oppressive," "confined," and "relaxed" were applied, and they were further made to link with interior design elements such as seats, pillars, and the windshield. Another car interior design that underwent the application of Kansei Engineering was studied by Jindo and Hirasago (1997). In that study, the design elements of the speedometer and the steering wheel of a passenger car were made to link with eight Kansei words.

Kansei Engineering was applied to the design of construction machinery that would take into account its users human sensibilities and psychological comfort (Nakada, 1997). In the electrical industry, Kansei Engineering was applied to develop a new color scale system for voltage visualization (Mitsui and Christie, 1997). With the new color scale system, users' needs could be better observed. Kansei Engineering has been used to measure the effectiveness of different types of cosmetic packaging, for the purpose of engaging the factor of consumer participation into the product design (Sedgwick et al., 2003).

Kansei Engineering is also used in the apparel industry. For instance, in the studies of Anitawati et al. (2007), Anitawati et al. (2008), and Lokman et al. (2008), Kansei words were used for the customers' expression of their emotional responses to e-Commerce apparel websites. The resulting information will then be used by the marketing department to help establish areas for improvement and/or propose new requirements for the design department in the launching of new apparel products. In the work of Shieh and Cheng (2003), Kansei Engineering was used for developing an intelligent fabric retrieval system to assist in apparel design. Chen et al. (2009) matched the features of the fabric image (i.e., design parameters) to the feelings of the customer and/or designer by applying the KE approach. Finally, in the work of Shimizu et al.(2004), KE words were used to search for apparel products in a proprietary database system.

From the literature survey and analysis, it has been found that there is a generic procedure for any application of the KE approach to particular domains of problems (e.g., car, chair, apparel, etc.), and that procedure consists of the following steps: (1) Determination of the Kansei words used in the particular domains of problems; (2) Determination of the design elements or design parameters of the type of product in the particular domain of application; (3) Building of the relationship between the Kansei words and the design elements or design parameters.

The major challenges with the above procedure to a particular application are as follows. Challenge 1: how to ensure the semantic soundness of the Kansei words compiled for a particular application domain. Challenge 2: how to ensure the completeness of the Kansei words compiled for a particular application domain. Challenge 3: how to ensure the validity of the relationship between the Kansei words and the design parameters. The current literature on apparel design has not adequately resolved the aforementioned challenges.

Regarding the first challenge, the current literature on apparel design has missed the context-sensitive nature of the semantics of a word. The semantics of words or expressions in both cognition and emotion is highly context-sensitive – i.e., the same word may have quite different meanings in different contexts (Zhang, 1994). "Beautiful car" and "beautiful apparel" arouse different emotions in the mind systems of humans, though in both contexts, the same word "beautiful" is used. In the current KE literature, there is a notion called "Kansei words for general products," i.e., context-insensitive Kansei words. This is, in the author's view, of not much sense or use as regards design of a particular type of product (e.g., apparel). Nevertheless, in the area of aesthetes for apparel design, several works did compile Kansei words in the apparel domain. For instance, in the work of Lokman and Aziz (2010), 100 Kansei words were assembled that represented feelings evoked by children's apparel. In the work of Anitawati et al. (2007), 40 Kansei words were collected to represent feelings towards apparel. However, the process of compiling Kansei words in these works is not convincing in terms of the semantic soundness, a concern that will be discussed in the next section.

Regarding the second challenge, the current literature still evidences room for improvement. It is indeed difficult to prove the completeness of compilations Kansei words, as there is no benchmark test available. Therefore, the issue of completeness is much related to the source of information accessed in the collecting of Kansei words.

With regard to solving the third challenge, the approach of either regression or machine learning techniques will be applied (Nagamachi, 1995). For instance, Lokman and Aziz (2010) used a statistical analysis approach called "partical least squares regression," which can handle a huge number of variables (Ishihara et al., 2008; Lokman et al. 2009), to build the relationship between Kansei words and design elements for children's apparel. In the work of Ishihara et al. (1997), the combination of applying Neural Networks and principal component technologies was used to build a relationship between the Kansei words and shoe images.

2.4 Data mining

2.4.1 Data-mining technology for compiling affective words

The definition of data-mining technology was provided in Section 2.1 of this thesis. The data-mining technology has been used in many applications, such as marketing (Ngai et al., 2009) and medical (Antonie et al., 2001), and was employed by Wang (2008) to compile Kansei words in the area of vehicle body design. Wang's approach comprises three phases: (1) raw data collection, (2) data structuring, and (3) noise reduction. In the raw data collection phase, there are three tasks. Task 1 involves finding the Web sources; Task 2 entails browsing the automotive related articles in the source; and Task 3 involves collecting articles from the website by a proprietary code developed by Wang. In the data-structuring phase, a TF-IDF (term frequency-inverse document frequency) matrix is constructed wherein TF (term frequency) indicates term frequency and IDF (inverse document frequency) indicates inverse document frequency, for noise reduction. In the noise reduction phase, IDF is used as a reference for evaluating the popularity of descriptive adjectives.

The above approach is semi-automatic, mission-specific, and content-consistent (Wang, 2008), which should be an improvement over any manual method in terms of the semantics soundness and completeness of the Kansei words collected. However, the approach of Wang (2008) is so-called syntactical-based (Zhao et al., 2015); that is, the selection of Kansei words is based only on the word appearance behavior in the source of the data, such as how many times a word appears in a document and so on. The basic idea of the approach is in fact to use the syntactic information to infer the semantic information. To the best knowledge of the author of this thesis, no other study exists that applies data-mining technology to compile Kansei words.

2.4.2 Apparel design parameters

Design results need to be described in the form of parameters, i.e., design parameter (DP). Although while the design description may not necessarily be represented by the parameter but rather via a drawing or image, the form of the description in a parameter can facilitate the computer processing, i.e., CAD (see Section 2.1 for definition of CAD).

The DP vocabulary depends on the requirements for the apparel. If the requirement includes functionality only, then there is DP vocabulary only for the function. In the literature, the source for the DP vocabulary is mainly data regarding the material, geometry, and appearance. For instance, Na (2009) defined color and shape as the DP for apparel. Raunio (1982) defined the size, shape, and thermal comfort of the material as the DP. The following information DPs are taken from the source of the material, the geometry, and/or the appearance: color, style, and fabric (Moody et al., 2010); waist and length (Li & Li, 2012); and physical properties of the fabric (e.g., tensile strength, shear strength, warp and weft extensibility, and bending rigidity) (Mahar et al., 1989); bending stiffness, thickness, and weight (Ayada et al., 1991; Lim & Istook, 2011; Niwa et al., 1998); and damping (Charfi et al., 2006). Note that appendix A gives definitions for some of the foregoing DPs. Further, in this thesis the term ADP (Apparel Design Parameter) may be used, a term that is interchangeable with DP.

Further studies are available on the parameterization of DPs that address, for example, color and silhouette. The parameterization of color is made by a red-green-blue (RGB) model, a hue-saturation-lightness (HSL) model, and a hue-saturation-value (HSV) model (Schwarz et al., 1987; Wang, 2008). Silhouette is a geometric element that gives a solid image of an object with a focus on the outline of the object (see Definition 2.3 in Chapter 2). The apparel sihouette is a unique feature of the apparel, as it is linked to the emotion or affect aroused from the apparel by the person who wears it, e.g., beautiful, graceful, etc. The sihouette leads to behavioral styles and manners, which further arouse the elements of emotion or affect. In apparel, sihouette is determined by the size of the shoulder and the waist and the width of the hem, and is classified into shapes A, H, X, V, and O. Silhouette A indicates that the solid image of the apparel resembles the shape of the letter A (and so forth with H, X, V, and O).

In the author's findings, the current literature does not provide a comprehensive classification of DPs for apparel. Particularly, among the DPs as listed above, there is no explicit description of the relationship among them, a relationship that is a part of the ontology of the apparel or the conceptual model of the apparel. An apparel ontology model is necessary for effective CAD of apparel or effective application of Internet-based information and computing technology (I-ICT) for apparel. It should be noted that an effective I-ICT for the apparel industry is the key to realizing the concept of mass personalization of apparel.

2.4.3 The relationship between the apparel design parameter and affective word

Moody et al. (2010) studied the relationship between the affective word and design parameter in apparel design. In their work, the affective word covers the factors of mood, emotion, personality, and preference. Mood and emotion are measured on a specific scale called PANAS (positive and negative mood affect scale) (Watson et al., 1988), and personality is measured on a scale called NEO FFI (neuroticism, extroversion, openness, agreeableness, and conscientiousness) (Costa & McCrae, 1992; Costa & McCrae, 2000). Moody et al. (2010) further studied the relationship between the affective word and the apparel style (which falls into the category of ADP). They categorized the apparel style to types such as casual and formal using four attributes for further characterizations, namely, fit, color, brand, and fabric. Their finding was that there is a strong correlation between the style of apparel and mood and emotion. A side finding emerging from their work is that there is a strong correlation between consumer personality and his/her purchasing behavior. The contribution of Moody et al. provides proof that apparel style has connection with some of the affective behavior of the customer, although style is just one of the ADPs.

In Na's work (2009), the relationship between emotion and the apparel design parameter (particularly with regard to style) was studied. Emotion was represented by several paired adjectives, such as classic-modern and warm-cold. The ADP included skirt length, sleeve type, color tone, collar type, and skirt type. Their work showed that there is a strong correlation between emotion and apparel style. Studies similar to the two aforementioned can be found in Cho and Lee (2005), where the apparel evolution trend (style in particular) was found to be relevant to the social, political, economic, and cultural factors, and in Khalid and Helander (2006), where the feeling of pleasure was found to be relevant to the size, style, and color of the apparel.

The nature of the aforementioned studies is about provision of evidence to the hypothesis that there are correspondences between the affective response of the customer and the design parameter of apparel. The findings from these studies have laid a foundation for establishing the quantitative relationship between the affective word and design parameter in the context of apparel design – and in particular, the mapping from the affective word to the design parameter of apparel.

2.5 Concluding remarks

The desire of the customer for apparel in the current and future modern eras can be fulfilled by mass personalization. The current I-ICT is promising with regard to the implementation of the mass personalization paradigm in the apparel industry. However, the foregoing literature review and analysis reveals several areas for improvement of apparel design and production. These areas are: (1) Lack of an ontology or conceptual model for apparel in the context of design and production, wherein the ADP is defined and measured; (2) Lack of a systematic and rational design process model for apparel, with which the open-endedness and iteration of the apparel design process could be captured; and (3) Lack of a comprehensive database that includes the affective words and their relationship with design parameters. Therefore, the proposed research with the three objectives as presented in chapter 1 is worthwhile, because they promise to fill the above-described knowledge gap.

CHAPTER 3 CONCEPTUAL MODEL OF APPAREL PRODUCTS

This chapter presents a conceptual model or an ontology model for apparel. Section 3.1 defines the conceptual model. Section 3.2 presents the tool used for building the conceptual model. Section 3.3 describes the development of the conceptual model. Section 3.4 illustrates the usefulness and presents the justification of the conceptual model as developed. Section 3.5 gives the conclusion. It is noted that the conceptual model here only represents the apparel structure information. Part of the work described in this chapter appears in the following publications: Zhao, Y., Dai, F., Gupta, M. M. & Zhang, W.J., Ontology Modeling for Intelligent Computer-Aided Design of Apparel Products, Int. J. of Automation Technology, 2015. Vol. 10. No. 2, 144-152; and Zhao, Y., Dai, F., Gupta, M. M. & Zhang, W.J., On conceptual modeling of apparel products, Proc. CAD'15, London, UK, 2015, 237-242.

3.1 The concept of conceptual model in the case of apparel

Apparel is viewed as a product (Carr & Pomeroy, 1992) and is a generic name for all types of clothes. As any other product, the development of apparel products needs computer support in order to meet the ever-increasing demands from the customer, including a shorter product delivery time, higher quality of the product, and lower cost plus the additional attributes such that a product should be ergonomic, aesthetic, and sustainable.

Effective computer support requires effective communication between the computer and human, and this requires a conceptual or domain model of the underlying application, apparel in our case. Further, a domain model needs to be expressed in a way to facilitate the computer's representation. A domain model captures basic concepts and their relations, and it forms a framework for the knowledge about a domain of an application (e.g., apparel). Interested readers may refer to the following paper for the definition of domain models (Wang et al., 2013). A domain model is also called an ontology model when the model's developer stands on the knowledge of knowledge in a domain. In this chapter, the three terms (i.e., domain model, conceptual model, and ontology model) are used interchangeably. Another expectation from a domain model is that it should be expressed in a way that it can facilitate communications among humans, who are the personnel involved in the development of a product. That said; a domain model should be highly semantic or meaningful; see Zhang (1994) for the definition of semantics.

Unfortunately, the development of a domain model is not quite addressed in the literature (in the area of apparel, there is almost no domain model in the literature to the best of the author's knowledge). In this chapter, a domain model itself is viewed as a "product" under design or development, and then a domain model is constructed via design thinking, in particular, applying the design theory and methodology such as axiomatic design theory (Suh, 2001). It is noted that this type of approach was taken by Bi et al. (2010) in developing the architecture of modular robots.

By design thinking, first, there is a need to formulate a requirement model for the domain model. There are three general functional requirements (FRs) for the domain model of an application. The first functional requirement (FR1) is that a domain model must capture all basic concepts and their relationships underlying a particular application concerned (e.g., apparel in this case). The second functional requirement (FR2) is that a domain model is a facilitator for the communication between the human and computer. The third functional requirement (FR3) is that a domain model is a facilitator for the communication among all personnel involved in product development (Zhao et al. 2015). The next section will present a tool with which to develop a domain model for apparel to meet the foregoing requirements.

3.2 Domain model development tool

For domain or conceptual modeling, there is a need for a tool, which is like a language. A language has vocabularies, grammatical rules for the vocabularies, and presentation methods for both the vocabularies and rules. For instance, in human natural languages, such as Chinese, English, German, etc., each has its grammatical rules and its presentation method. It is noted that concepts and their relationships are considered as data. Therefore, the term "data modeling" is an activity that refers to conceptual modeling, ontology modeling, and domain modeling. Note that data contains both information and knowledge. Details about the definition of data, information and knowledge can be found in (Zhang, 1994). For the description of the grammar of data modeling language, the terms "construct" and "integrity rule" (which is applied to the construct) are used. Further, for data modeling language, both the diagrammatic presentation and textual presentation may be available to represent the model. In particular, the diagrammatic representation is favored for communications among humans (with respect to FR3), while the textual presentation is favored for human and computer communications (with respect to FR2).

In this chapter, the modeling language developed by Zhang (1994) is used owing to its simplicity as well as sufficiency to meet the three general requirements for data modeling (as mentioned before). In Zhang (1994), the basic language grammar or construct is shown in Figure 3.1. In Figure 3.1, the concepts or constructs of class, attribute, and type are presumably known to the reader. Member attribute refers to attributes that characterize individual instances under the attributes. Class attribute refers to attributes that characterize the class as a whole. The construct “has-a” describes the data abstraction of an emergent property aggregated from a set of attributes. For instance, attributes of “professor,” “student,” “support staff,” and so on are aggregated into a new concept called “university.” One can then say: “a university has professors, students, and support staff, and so on.” The sense of emergent data with “university” here is relative to the concepts of “professor,” “student,” “support staff,” and so on; that is, one first has the concept of professor, student, support staff, and one then comes up with the concept of university by bringing together the concepts of professor, student, and support staff (i.e., aggregation) with additional structural relationships among the composing attributes (“professor,” “student,” “support staff”) (e.g., the semantics: “a professor trains a student with the help of a support staff”).

Further in Figure 3.1, the construct “is-a” describes the knowledge that among A, B, and C, there may be such knowledge that A represents the common feature or characteristic of B and C. For instance, “A is animal, B is human, and C is monkey.” Then, “A is the common feature of B and C,” that is, one can say “Human is a kind of animal”, “Monkey is a kind of animal” and so on.

Figure 3.2 is a construct called “association.” Two class objects can be associated by any reason that appears (L1, L2) on the edge that connects A and B. For instance, “A is the temperature, and B is the number of people in a park.” A and B may be associated with each other if there is a relationship between them such that “the higher the temperature, the more people go to the park.” Note that the foregoing example is called a “specialized association.” Therefore, association is a generic relationship between A and B. The association may have a direction in that A may be a cause for B (Figure 3.2(b)). This association is also called a “casual relation,” which is incorporated in a data-modeling language, and this finding was first made by Wang et al. (2013). It is also noted that both A and B are objects which can be instances, classes, or types according to the object relativity principle (Smith & Smith, 1978) or information relativity principle (Zhang, 1994).

Figure 3.3 shows a construct called "grouping". Given a set of objects say U1, U2, grouping is applied to them, which leads to a situation that U1 and U2 are put together with some reason and play a new or emergent function or role. Emergent means that the role of a group is different from the roles of U1 and U2 (if they stand alone) in quality and/or quantity. A grouped object (G in Figure 3.3) may have its own attributes. Grouping differs from association in that objects in a group do not have any additional relationship and they are in one group because they satisfy the group membership criterion.

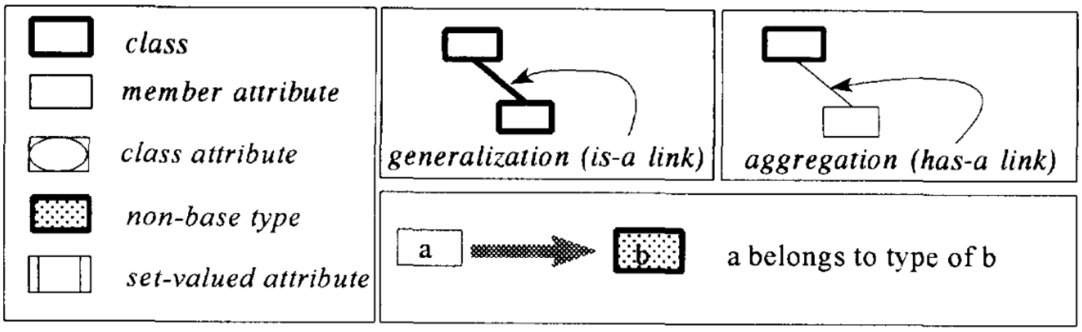


Figure 3.1 Diagram representation of basic building blocks (Zhang, 1994)

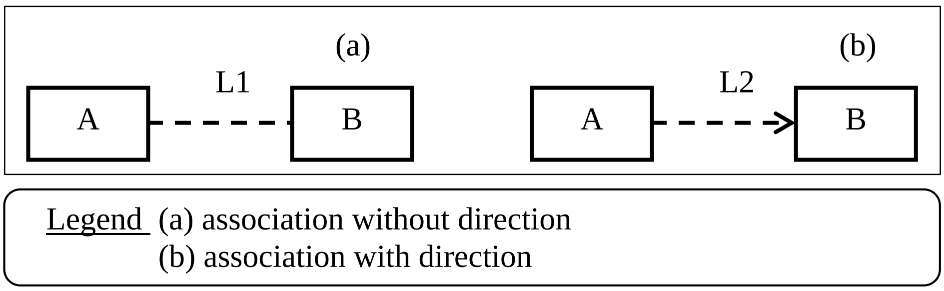


Figure 3.2 The diagram representation of association

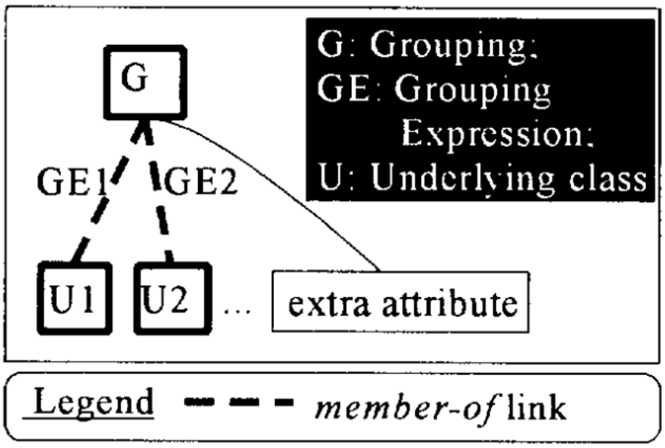


Figure 3.3 Definition of grouping (Zhang, 1994)

3.3 Conceptual model of apparel products

3.3.1 Semantics of apparel

Semantics of apparel refer to descriptions of basic concepts and their relationships in the domain of apparel. An apparel product (e.g., dress) is made by assembling 2D patterns. A 2D pattern consists of a block, a number of eases, a number of darts, and a number of gathers. Since the human body consists of the upper part, lower part, legs, and arms, there are the upper apparel, lower apparel, leg apparel, and arm apparel, and accordingly there are the upper patterns, lower patterns, leg patterns and arm patterns. The upper pattern is developed from the bodice block, and the sleeve pattern is developed by taking the interface of bodice block as a reference and defining the shape of arms from the interface (RE: Figure 2.2). The lower pattern is developed from the skirt block, and the leg pattern is developed by taking the interface of skirt block as a reference and defining the shape of legs from the interface (RE: Figure 2.3). Apparel may also need to cover a neck. The pattern to cover a neck is called a collar pattern. Collar pattern is developed based on the bodice block. Other apparel patterns, such as placket, cuff, or pocket, may appear on particular apparel products, depending on the style and function of an apparel product.

It should be noted that in the apparel design community, upper is called top, and lower is called bottom. So the top apparel and pattern replace the upper apparel and pattern, and the bottom apparel and pattern replace the lower apparel and pattern. Assembly of 2D patterns results in a 3D apparel product.

3.3.2 The conceptual model

Figure 3.4 expresses that for any kind of apparel there is the information of product ID (identity), name, type, and pattern. The model of Figure 3.4 makes sense to a part of apparel such as sleeve. In Figure 3.4, the notation (i.e., a box with a double vertical bar side) expresses that an apparel product consists of a set of 2D patterns. Figure 3.5 expresses that there are a variety of types of apparel, and apparel is a generic notion for all types of apparel; for example, a dress is a kind of apparel, a skirt is a kind of apparel and so on.

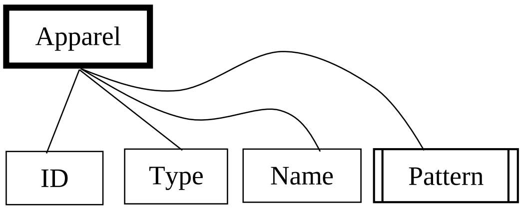


Figure 3.4 Data representation of apparel

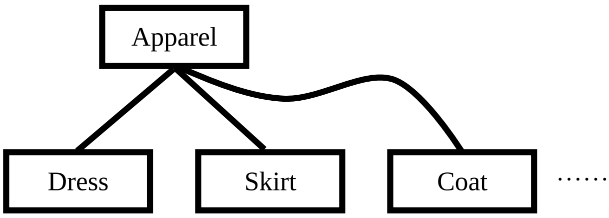


Figure 3.5 Data representation of types of apparel

Figure 3.6 shows that a particular pattern is developed by starting with a block and thus, a pattern has the information of block. Further, a pattern may have several eases, darts, and/or gathers. Figure 3.7 expresses the information of the block. In particular, there are two types of blocks (i.e., skirt and bodice) (Figure 3.8), and for a particular piece of block, its complete geometry is determined by the dimensions of individual human bodies, such as the waist. The detailed description of a block instance (i.e., a particular block under design) is described in the attribute “Detailed description” (Figure 3.7). The detailed description refers to the description of a particular block in a coordinate system or frame for short (Figure 3.9). In particular, the frame is used for giving a complete specification of a pattern. Block is composed of a set of block elements (e.g., element 1-2, element 2-3, element 3-4, and element 4-5, element 5-6, element 6-7, element 7-8 and element 8-1) (in Figure 3.9). Under the coordinate system or frame, geometry of the block can be accurately described.

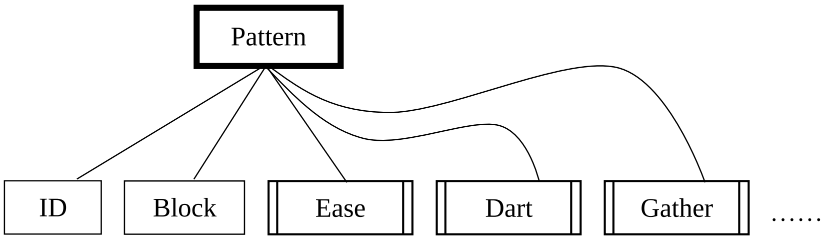


Figure 3.6 Data representation of pattern

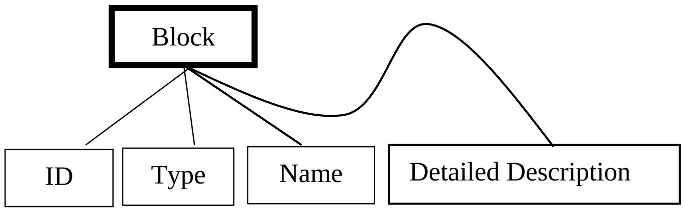


Figure 3.7 Data representation of block

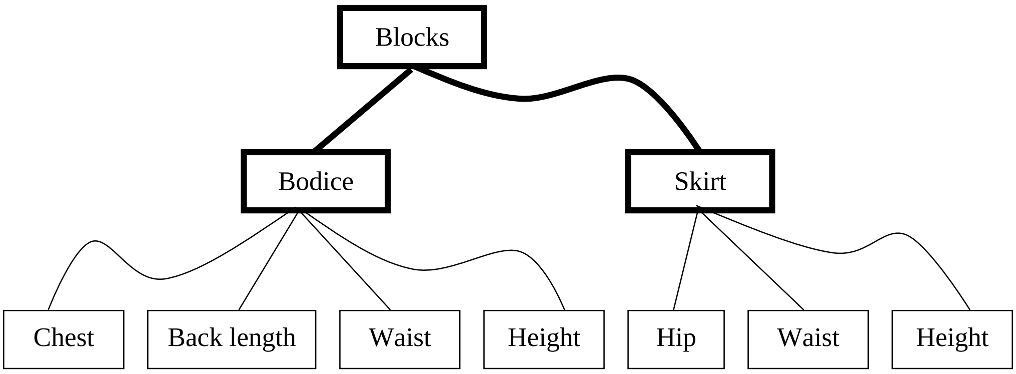


Figure 3.8 Data representation of types of block

Figure 3.10 shows the relationship among the block, ease, dart, and gather. In particular, an ease is expanded from a block, resulting in "block-ease," that is the block-ease is a "sum" of the block and ease. Dart and gather are associated with the block-ease in that both dart and gather are defined extended from the block-ease in the same reference coordinate system.

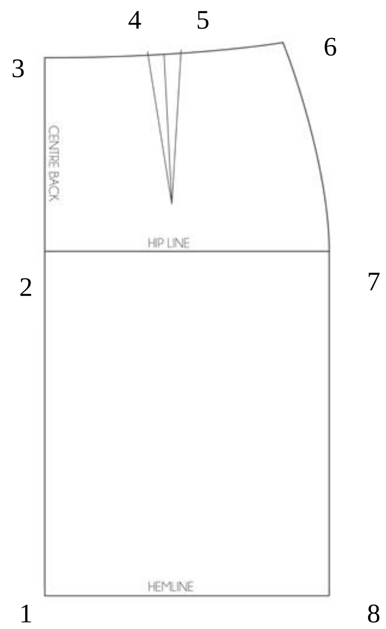
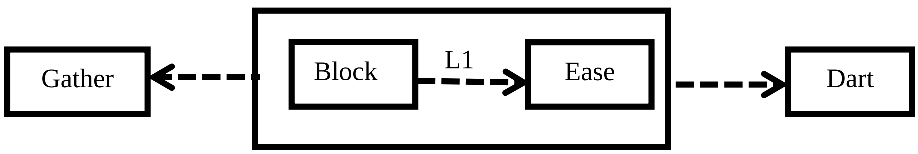


Figure 3.9 Detailed description of skirt block (http://static1.squarespace.com/static/534d1b21e4b077040469bae0/t/544f56cae4b07bff886a6ac9/1414485706733/make+a+wrap+skirt_2. Retrieved September 10, 2014)



L1: expanded (ease is expanded from block)

Figure 3.10 The relationship among the block, ease, dart, and gather

Figure 3.11 shows that an apparel product is assembled from a set of 2D patterns (see the notation of the set-valued attribute for the 2D pattern in Figure 3.11). Figure 3.11 also represents how the 2D pattern and 3D apparel are associated with each other such that they share the same attributes of "ID," "Name," "Type," "Patterns." The 3D apparel product includes the pattern-pattern assembly, and its details are represented by another data model "Pattern-Pattern Assembly" (Figure 3.12).

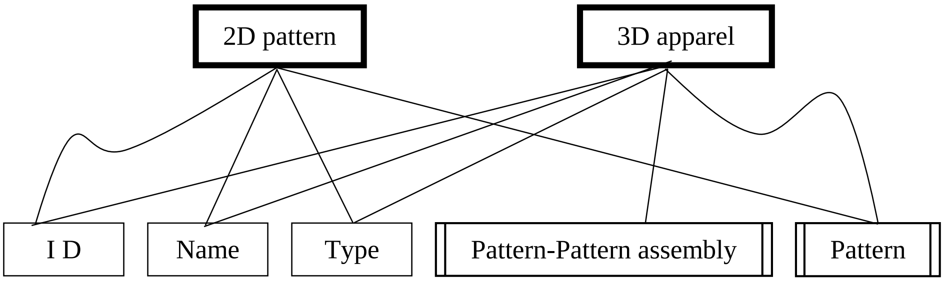


Figure 3.11 Data representation of 2D pattern and 3D apparel

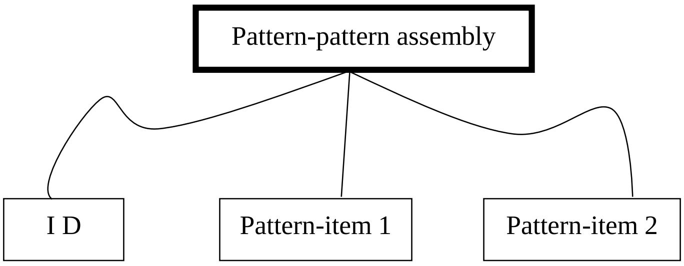


Figure 3.12 Data representation of pattern-pattern assembly

3.4 Evaluation of the conceptual model

This section evaluates the conceptual model or ontology model developed above. For FR1, the process of developing the model speaks of its fulfillment of FR1. FR3 is satisfied with the diagrammatic presentation of the model, as humans are inherently responsive to a diagram as opposed to a text. Further, in order to illustrate how FR2 is satisfied, a case is partially constructed of integration of the design based on the 2D pattern of apparel and the design based on the 3D apparel with the conceptual model in the following.

Assume that there are two interfaces of CADOA: one for the 2D pattern called "2D-I", and the other for 3D pattern called "3D-I". The skirt is first constructed in the 2D-I, say 2D skirt, and a corresponding 3D skirt is assembled from the 2D skirt and displayed in the 3D-I. After that, the designer makes a change on the 3D skirt in the 3D-I, and the change is made available on the 2D skirt in the 2D-I automatically (i.e., computer-generated). At the logical level, both the 2D skirt and 3D skirt are described in data with the conceptual model as developed before. Note that in order to facilitate the computer implementation, the conceptual model as developed before can further be converted to the UML (universal modeling language) model (as UML is a standard data-modeling language known or interpretable to many computer software systems). At the implementation level, the existing software called ARTEX Design & Grading System

(ARTEXDGS) can be employed for the 2D-I to display the 2D skirt and the software called Marvelous Designer (MD) is employed for the 3D-I to display the 3D skirt. The ARTEXDGS and MD each have a different data format to store the information, called the ARTEXDGS data model and MD data model, respectively. The following algorithms can be constructed to realize the foregoing script of the integration of two CADOA interfaces.

Pre-condition (the 2D skirt is displayed on the ARTEXDGS interface):

(1) Algorithm Ⅰ: convert the ARTEXDGS data model for the 2D skirt to the UML model for the 2D skirt.
(2) Algorithm Ⅱ: convert the UML model for the 2D skirt to the UML model for the 3D skirt.
(3) Algorithm Ⅲ: convert the UML model for the 3D skirt to the MD data model for the 3D skirt (then display).

Post-condition (the 3D skirt is displayed on the MD interface; a change is made on the 3D skirt on the MD interface, i.e., 3D-I):

(4) Algorithm Ⅳ: convert the UML model for the 3D skirt to the UML model for the 2D skirt.
(5) Algorithm Ⅴ: convert the UML model for the 2D skirt to the ARTEXDGS data model for the 2D skirt.

Post-condition (the changed 2D skirt is displayed on the ARTEXDGS interface, i.e., 2D-I):

Without loss of generality, in the following, only the construction of Algorithm Ⅱ is illustrated. Figure 3.13 shows the UML model of the conceptual model of the connection or linkage of the 2D pattern to the 3D apparel (RE: Figure 3.4, Figure 3.5, Figure 3.6, Figure 3.11 and Figure 3.12). Figure 3.14 shows the UML model of the conceptual model of the block (RE: Figure 3.7, Figure 3.8 and Figure 3.10). Note that the UML models are templates and to a particular skirt, an instance is constructed in conformity to the UML template of the skirt. Particularly, three algorithms ("block to pattern," "2D pattern composing," "2D pattern to 3D apparel"), corresponding to Algorithm Ⅱ, are developed (see appendix B). The first algorithm is the description of the layout of 2D skirt pattern (front and back) from the skirt block (Figure 3.15(a)), which is described by dots. The second algorithm is to get the 2D skirt pattern (front and back) from the dots generated from the first algorithm with lines (Figure 3.15(b)). The third algorithm is to assemble the 2D skirt patterns generated from the second algorithm into a 3D shape (Figure 3.15(c)). Details of these algorithms can be found in appendix B.

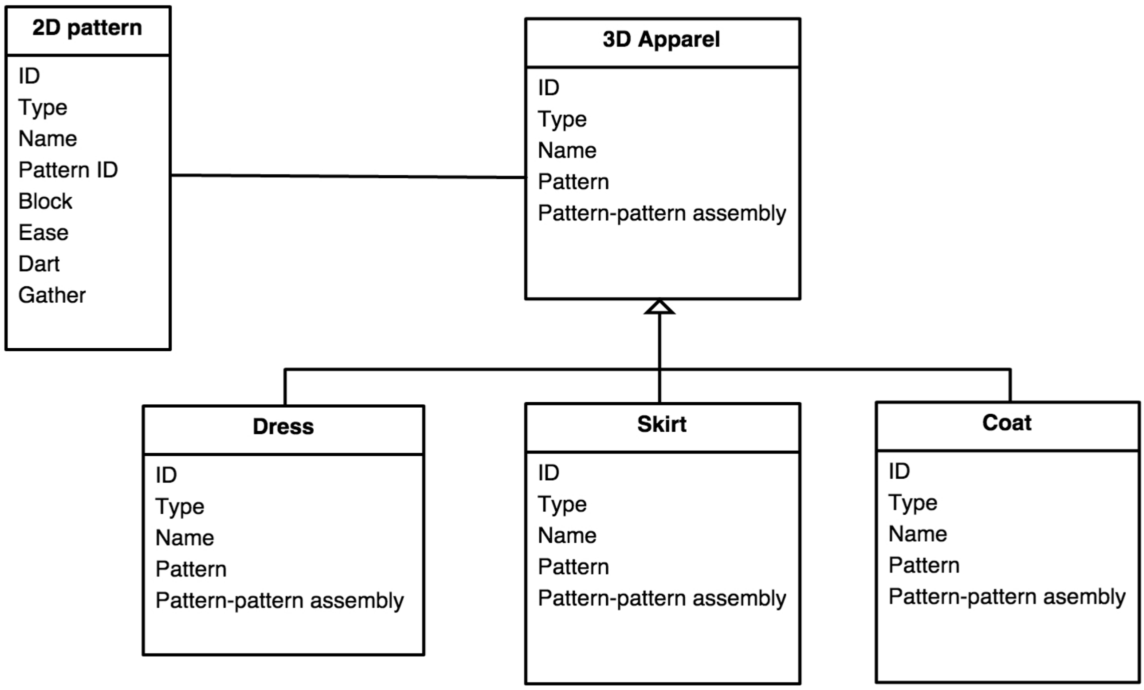


Figure 3.13 Data representation of the 2D pattern and 3D apparel in UML

The above case study not only shows the role of the conceptual model in facilitating the communication between the human and computer but also the role of the conceptual model in facilitating the communication among humans. This second facilitator makes sense in that different views of an apparel product, the 2D view and 3D view in this case, can be supported and further enabled with the conceptual model. Note that at a certain point of design, the 2D view of products is necessary, while at another certain point of design, the 3D view of products is necessary. Support to both of the views automatically is the evidence that the computer-aided design system can facilitate the human-to-human communication in design.

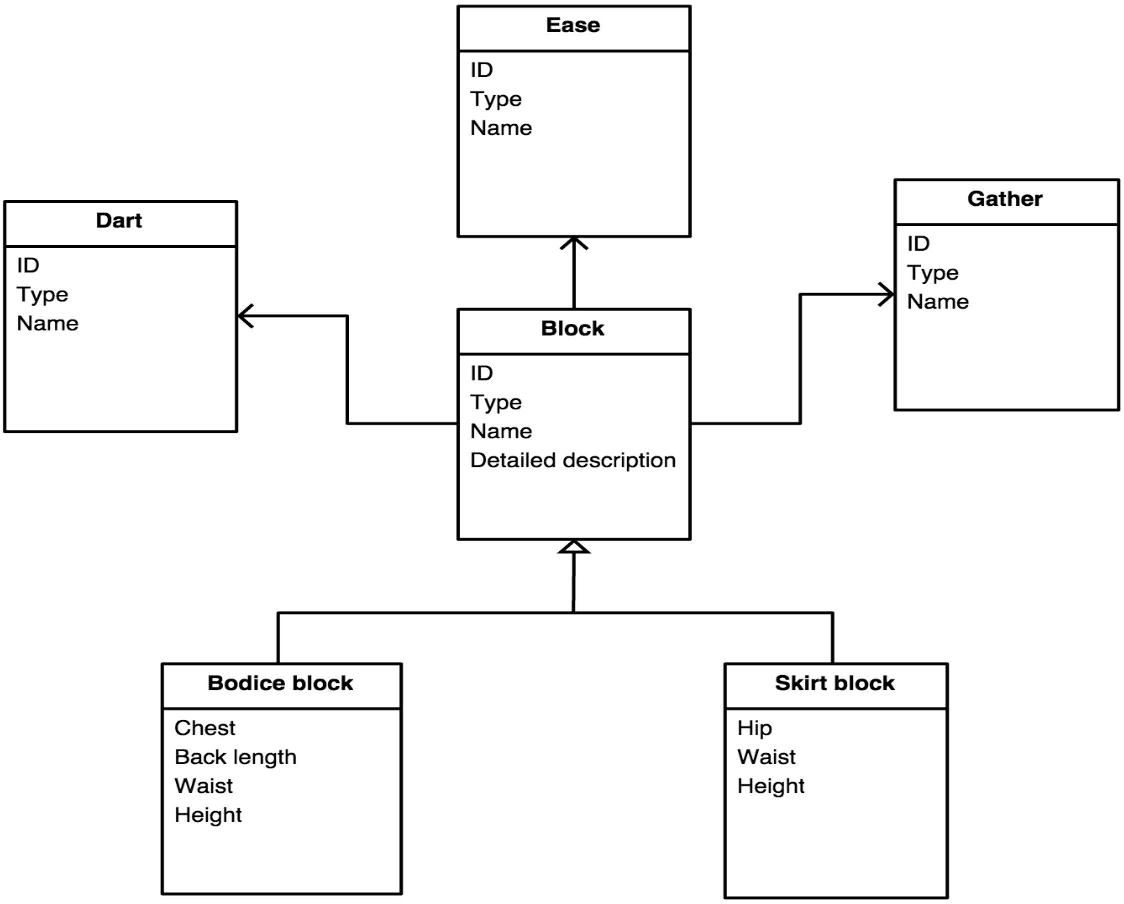


Figure 3.14 Data representation of the block in UML

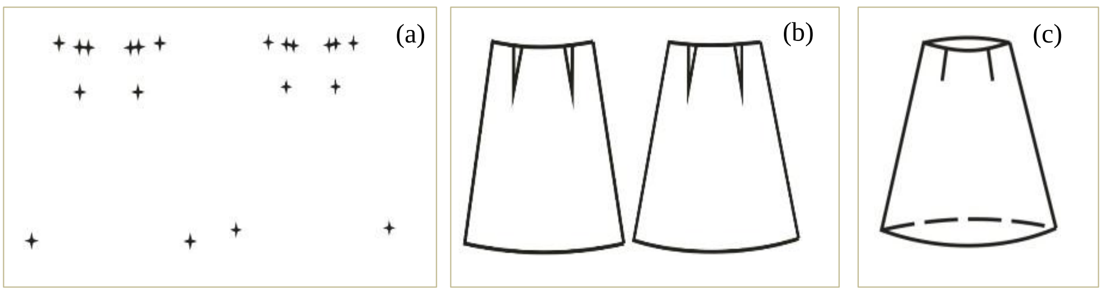


Figure 3.15 The illustrations for the algorithm which converts the UML model for the 2D skirt to the UML model for the 3D skirt

3.5 Concluding remarks

In this chapter, a conceptual model for apparel products was proposed. The model describes the basic concepts and their relationships in the domain of apparel design and manufacturing. The model is generic in that it is a template while a particular apparel product under design is conducted with the template. In other words, all individual designs (or instances) can make use of the model. The model is also general in that all types of apparel are covered by the model. The model is a semantic one that meets the requirement of facilitating the human-computer communication. Note that details regarding the concept of conceptual model or view can also be found from the standard database text, particularly the SPARC database architecture (Date, 1986).

The conceptual model was further developed into a UML model that allows the detailed specification of data and the model potentially to be supported by a wide spectrum of software systems. With the UML model, one can readily develop various external models or computer-aided systems to provide a more intelligent computer aid to apparel. The example used in this chapter has proved the effectiveness and usefulness of the conceptual model of apparel in terms of its capability to integrate different CADOA systems and in terms of facilitating the communication between the human designer and CADOA system (due to a more “common” language and semantics between the human and computer). The future work will be directed to implement all the algorithms as mentioned in the case study (Section 3.4), although it seems that the implementation is entirely possible and is a matter of routine computing and coding efforts.

CHAPTER 4 A SYSTEMATIC DESIGN PROCESS FOR APPAREL PRODUCTS

The goal of this chapter is to develop a systematic design process for apparel products. To achieve this goal, a general product design process is introduced, which is a guideline for developing a systematic apparel design process (SADP) (Section 4.1). Section 4.2 presents details of the SADP, including activities in each design phase, which gives a background for discussing the issue of computer support for “affective design” of apparel (in Chapter 6). Section 4.3 illustrates the usefulness and benefit of the SADP, and the conclusion is given in Section 4.4. Part of the research described here appears in the following publication: Zhao, Y., He, D., & Zhang, W. J., Toward a systematic design process model for apparel products, ASME IMCE, Houston, USA, Nov. 13-19, 2015. To appear.

4.1 General product design process

Nowadays, apparel design has undergone a huge change, involving much more complex processes for not only function, but also comfort and pleasure (Lin & Zhang, 2006). Apparel design should be able to take advantage of general product design theory and methodology, as apparel is in fact a kind of product. An important enabler in general design theory and methodology, which makes a general design process more systematic and rational, is the concept of design phase (Pahl et al., 2007) (i.e., design is divided into three phases: conceptual design, embodiment design, and detail design).

The goal of conceptual design is to determine the working principle of a product, which fulfills the requirement (which is in general characterized by the attributes such as function, comfort, and pleasure). Working principle refers to why and how a structural element of the product works to meet a particular requirement. The goal of embodiment design is to determine the attributes that represent the product structure in terms of space, volume, and material. The goal of detail design is to determine the attributes that represent the product structure in terms of appearance and a surface.

There is no doubt that design can be viewed as problem solving. The problem represents what and how to meet the requirement and the condition upon which a solution is effective to a problem. Figure 4.1 shows the concept of design phase in the framework of problem solving.

From Figure 4.1, it can be seen that the concept of design phase divides the design activities into three groups such that the activity in the conceptual design should be carried out before that in the embodiment design.

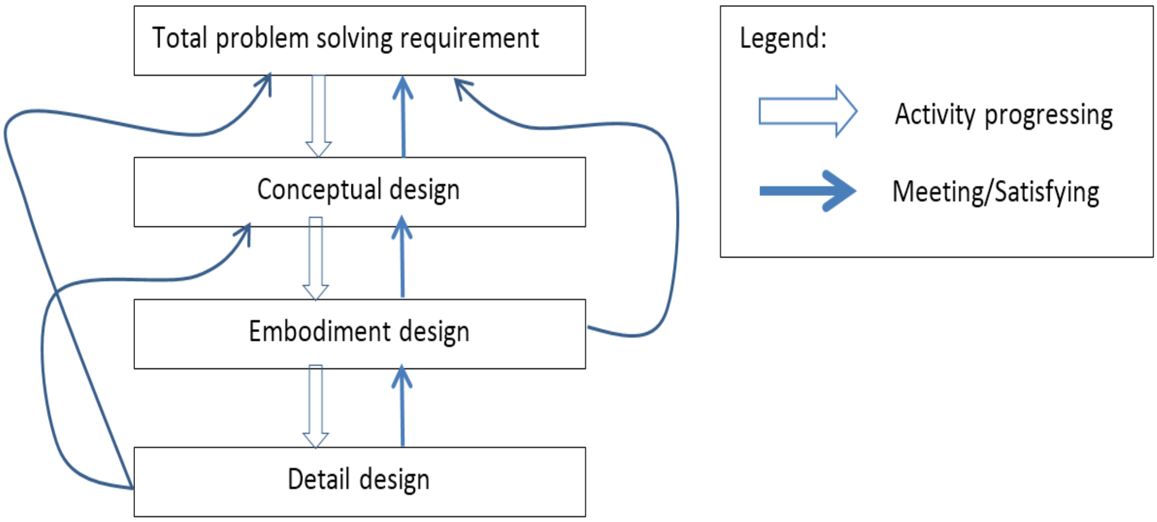


Figure 4.1 Requirement, conceptual design, embodiment design, and detail design: problem solving

In the following, the concept of design phase in the general design theory and methodology is tailored to apparel design, leading to a new apparel design process. It must be emphasized that the aforementioned definition of the design phase concept is limited where the requirement of a product is primarily functional in nature. This limit needs to be resolved in apparel design, as an apparel product has a high need for the wearer to express human affect. Further, in general design theory, design specification, is developed before conceptual design. Therefore, the general design theory and methodology divides apparel design into the following phases: (1) requirement, (2) specification development, (3) conceptual design, (4) embodiment design, and (5) detail design. For simplicity, in the following discussion, the foregoing design process for apparel is called systematic apparel design process (SADP).

4.2 Systematic apparel design process (SADP) development

4.2.1 Design requirement model

For apparel, the requirement includes not only the functional aspect but also the affective aspect. The requirement of an apparel design is further characterized by the aspects of (1) function, (2) fit to the body, (3) ease for comfort and moving, (4) expression of personality, (5) feeling of beauty. The first three aspects may be straightforward, while the fourth one needs some explanation.

The expression of personality refers to the wearer's state of mind about how the wearer would be perceived by an audience when wearing apparel. This seems to be close to the concept called "expressive" in the work of Lamb & Kallal (1992). However, in their work, Lamb and Kallal used the "expressive" only to mean the expression of a message. The "feeling of beauty" refers to a wearer's positively affective response when wearing the apparel. Further, in all these aspects, the specific target values in apparel design are also given. In the requirement model, some administrative information may also be included, such as (1) wearer information; (2) name of the apparel; (3) date of updating the requirement; (4) the person who is responsible for each requirement; (5) version/index number of each requirement; (6) date of the product delivery; (7) cost of the product; (8) priority that each requirement is satisfied (Pahl et al., 2007).

4.2.2 Conceptual design model repository

According to the definition of the conceptual design phase (as mentioned before), the following decisions need to be made: (1) Apparel style, which illustrates the distinctive features of apparel that describe humans' personality, e.g., relaxing, graceful, etc., (2) Silhouette, which describes the outline or general shape of apparel (see Definition 2.3 in Chapter 2), (3) Requirement structure model, which is a set of requirements over the body or work domain (R in Figure 4.2(a)), (4) Principle, which governs the design parameter to meet the requirement (P in Figure 4.2(a), (b)) and which in itself can be regarded as a kind of design parameter (D in Figure 4.2).

It is noted that the requirement may not be found achievable by any principle and in this case the requirement needs to be decomposed into "smaller" or "simpler" ones (Figure 4.2(c)). Accordingly, the principle with the design parameter will need to be decomposed (Figure 4.2(c)). Further, principle is not design parameter but two are closely related. While a designer actually presents the design parameter in texts or diagrams, the underlying reason for the design parameter to fulfill the requirement is the principle.

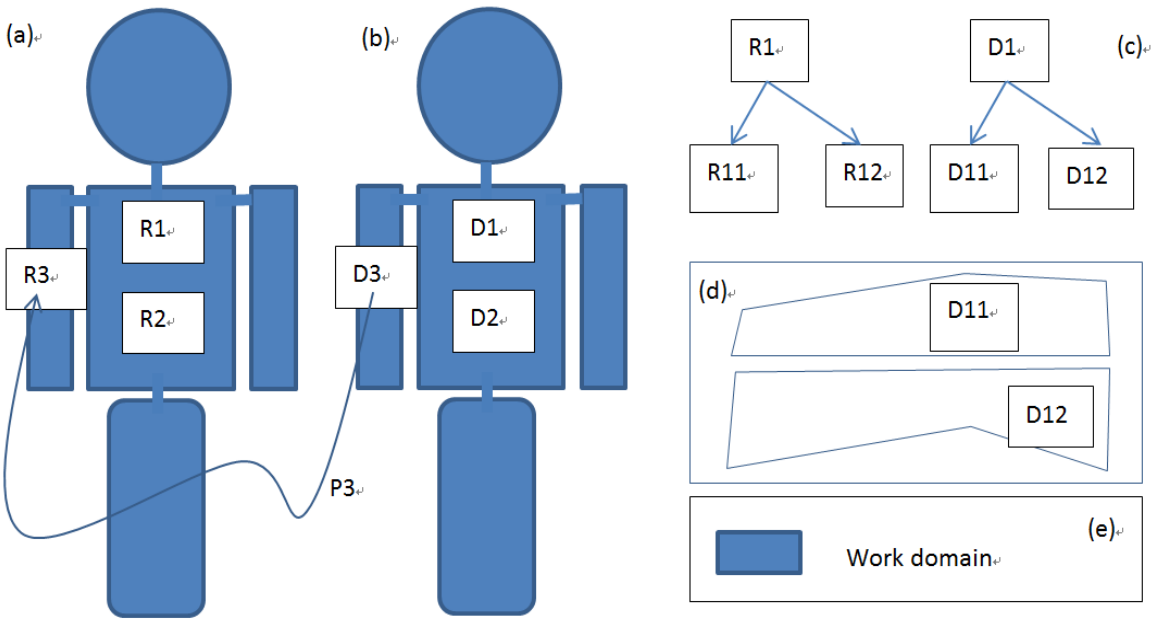


Figure 4.2 Conceptual design information repository

R: requirement; D: design parameter; P: principle; (a) work domain or design domain; (b) design parameter with principle; (c) requirement structure and design parameter; (d) pattern (two dimensional pieces of materials)

4.2.3 Embodiment design information repository

According to the definition of embodiment design (as mentioned before), the decisions that should be made are: (1) Design parameter of the apparel which describes a set of characteristics of apparel (D in Figure 4.2(b), (c)); (2) Illustration; (3) Color of the material; (4) Texture of the material.

4.2.4 Detail design information repository

According to the definition of detail design (as mentioned before), the decisions to be made are: (1) Fabric and trim information (Figure 4.3), where the detailed features of fabric and trim, such as color, quality and content, are specified. (2) Specification sheet (Figure 4.4), where the detailed sizes for the apparel product are specified. (3) Point of measurement (Figure 4.5), where the measurement of the size in (2) is specified. (4) Bill of materials (Figure 4.6), where the materials for fabricating the apparel under design is specified. (5) Cost sheet (Figure 4.7), where the costs of fabric, trims, labor, and packing materials in terms of quality and quantity are specified. (6) Pattern size (Figure 4.8); in this connection, Figure 4.8 is an example of the so-called cap pattern, where the main sizes of the pattern are specified, such as the size of pocket. It is noted that not all the sizes are displayed on this sheet. (7) Grading for the mass customization (Figure 4.9), where different sizes of the apparel patterns, such as XXL, XL, L, M, S, XS, are constructed.

Fabric & Trim - Boyfriend Blazer

Date:	18-Aug-2010	Revised Date:	
Style #	FA11-209	Season:	Fall 2011
Size Range:	XS-XL	Classification:	Women's
Label:	Urban Outfitters	Group Name:	
Description:	Velour "boyfriend" blazer with gold button metal closure		

FABRIC INFORMATION			
Main Fabric:	Velour	Fabric 2:	Lining
Quality/Ref:	220 g/m²	Quality/Ref:	48 g/m²
Content:	80% Cotton/20% Polyester	Content:	100% Polyester
Wash/Finish:	Piece Dyed	Wash/Finish:	Piece Dyed
Fabric 3:	Interfacing	Fabric 4:	
Quality/Ref:	109 g/m²	Quality/Ref:	
Content:	100% Cotton	Content:	
Wash/Finish:	Piece Dyed - Fusible	Wash/Finish:	

TRIM INFORMATION			
Trim A:	Gold Metal Button	Trim B:	
Content:	100% Brass	Content:	
Reference #:	24361	Reference #:	
Location:	Center Front	Location:	

COLOR COMBINATIONS				
COLOR:	COMBO 1	COMBO 2	COMBO 3	COMBO 4
Combo Name	**Slate**	**Ink**	**Raspberry**	
Main Fabric	Velour	Velour	Velour	
Fabric 2	Black	Black	Black	
Fabric 3	Black	Black	Black	
Trim A	Brass	Brass	Brass	

Figure 4.3 Fabric and trim sheet

(http://haleylynnenagy.blogspot.ca/p/technical-work.html. Retrieved October 1, 2014)

Spec Sheet - Boyfriend Blazer

Date:	18-Aug-2010	Revised Date:	
Style #	FA11-209	Season:	Fall 2011
Size Range:	XS-XL	Classification:	Women's
Label:	Urban Outfitters	Group Name:	
Description:	Velour "boyfriend" blazer with gold button metal closure		

Sample Size: Small

	DATE:	18-Aug-2010 ORIGINAL REQ
POINT OF MEASURE:		
1.	Center Front Length	26"
2.	Center Back Length	25"
3.	Side Length	16 1/4"
4.	Chest Width Circumference TM	34"
5.	Across Shoulder	15"
6.	Across Chest	17 1/2"
7.	Across Back	15"
8.	Waist Width Circumference TM	33"
9.	Bottom Hem Height	1"
10.	Bottom Opening/Sweep TM	40"
11.	Shoulder Drop from HPS	2 1/2"
12.	Bicep (1" Down from Armhole) TM	12"
13.	Armhole Width Circumference TM	16"
14.	Sleeve Opening TM	10"
15.	Neck Width (HPS to HPS)	15 1/2"
16.	Front Neck Drop (HPS to Seam)	3 1/2"
17.	Back Neck Drop (HPS to Seam)	1/2"
18.	Lapel Width	2 1/2"
19.	Collar Length (Point to Point)	16 1/2"
20.	Collar Width (At CB)	2"
21.	Collar Stand Height	2 1/4"
22.	Bottom Pocket Placement from HPS	20 1/2"
23.	Bottom Pocket Placement from CF	4"
24.	Bottom Pocket Width	6 1/2"
25.	Bottom Pocket Length	3/8"

Front Sketch

Back Sketch

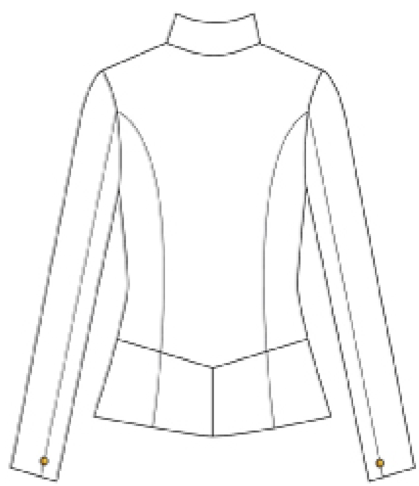


Figure 4.4 Specification sheet

(http://haleylynnenagy.blogspot.ca/p/technical-work.html. Retrieved October 1, 2014)

Point of Measurements - Boyfriend Blazer Front

Date:	18-Aug-2010		
Style #	FA11-209	Season:	Fall 2011
Size Range:	XS-XL	Classification:	Women's
Label:	Urban Outfitters	Group Name:	
Description:	Velour "boyfriend" blazer with gold button metal closure		

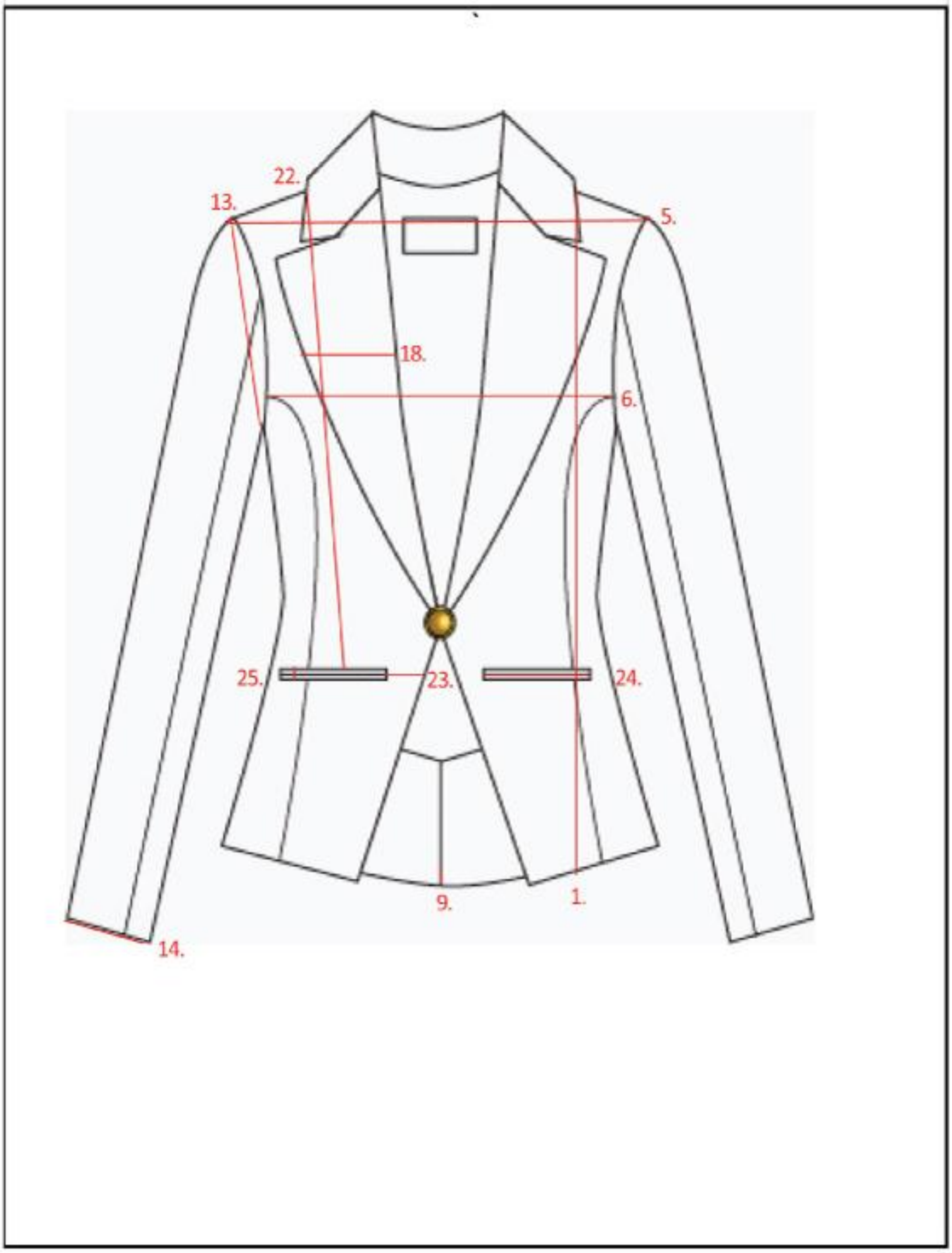


Figure 4.5 Point of measurements sheet (front)

(http://haleylynnenagy.blogspot.ca/p/technical-work.html. Retrieved October 1, 2014)

Bill of Materials - Boyfriend Blazer

Date:	18-Aug-2010	Revised Date:	
Style #	FA11-209	Season:	Fall 2011
Size Range:	XS-XL	Classification:	Women's
Label:	Urban Outfitters	Group Name:	
Description:	Velour "boyfriend" blazer with gold button metal closure		

Sample Size:	Small

Description	Color	Material	Size	Unit	Qty
Fabric:					
Velour	Slate/Ink/Raspberry	80% Cotton/20% Polyester	60"	YD	1.31
Lining	Black	100% Polyester	48"/60"	YD	1
Fusible Interfacing	Black	100% Cotton	112 cm	YD	1
Trims:					
Gold Metal Button	Gold	100% Brass	20mm	PC	1
Thread (Inside)	White	100% Cotton	1	Spool	1
Thread (Outside)	White	100% Cotton	1	Spool	1
Brand Label	Grey	100% Polyester Satin	1/2" x 1 1/2"	PC	1
Size Label	Grey	100% Polyester Satin	5/8" x 3/4"	PC	1
Theft Label	White	100% Polyester GrossGrain	2 3/8" x 2"	PC	1
Care/Content Label	White	100% Polyester Satin	7/8" x 1 3/4"	PC	1
Large Hang Tag	Tan/Brown	Cardboard	5 x 2" 1/4"	PC	1
Small Hang Tag	Tan/Brown	Cardboard	2 1/2" x 1"	PC	1
Stretch Hang Tag	Tan	Cardboard	1 1/4" x 3/4"	PC	1
Price Hang Tag	White	Cardboard	2 1/2" x 1 1/4"	PC	1
Sendouts:					

Figure 4.6 Bill of material sheet

(http://haleylynnenagy.blogspot.ca/p/technical-work.html. Retrieved October 1, 2014)

Cost Sheet - Boyfriend Blazer

Date:	18-Aug-2010	Revised Date:	
Style #	FA11-209	Season:	Fall 2011
Size Range:	XS-XL	Classification:	Women's
Label:	Urban Outfitters	Group Name:	
Description:	Velour "boyfriend" blazer with gold button metal closure		

COMPONENT COSTS:	Yds/Qty	Unit Prc	$ Amt
FABRIC COSTS:			
Velour	1.000	2.900	$2.900
Lining	1.000	2.900	$2.900
Interfacing	1.000	2.390	$2.390
(TOTAL FABRICS)			**$8.190**
TRIMS:			
Gold Metal Button	1.000	1.98	$1.980
Thread	1.000	0.150	$0.150
Brand Label	1.000	0.050	$0.050
Size Label	1.000	0.150	$0.150
Theft Label	1.000	0.070	$0.070
Care Content Label	1.000	0.500	$0.500
Large Hang Tag	1.000	0.500	$0.500
Small Hang Tag	1.000	0.500	$0.500
Stretch Hang Tag	1.000	0.500	$0.500
Price Hang Tag	1.000	0.500	$0.500
(TOTAL TRIMS)			**$4.900**
CMT/LABOR COSTS:			
Patterns	1.000	0.200	$0.200
Marking	1.000	0.150	$0.150
Grading	1.000	0.250	$0.250
Sewing	1.000	10.00	$10.000
(TOTAL LABOR)			**$10.600**
PACKING MATERIALS:			
Hanger	1.000	0.250	$0.250
Polybag	1.000	0.020	$0.020
Outer Box	1.000	0.075	$0.075
(TOTAL PACKING)			**$0.345**
FOB:			
Duty	1.000	0.250	$0.250
Air Freight	1.000	2.000	$2.000
Customs Broker Fees	1.000	0.075	$0.075
(TOTAL FOB)			**$2.325**
TOTAL COST			**$26.360**
WHOLESALE PRICE	100%	25.76	51.50
WHOLESALE MARGIN			25.14
RETAIL PRICE	100%		108.42

Front Sketch

Back Sketch

Figure 4.7 Cost sheet

(http://haleylynnenagy.blogspot.ca/p/technical-work.html. Retrieved October 1, 2014)

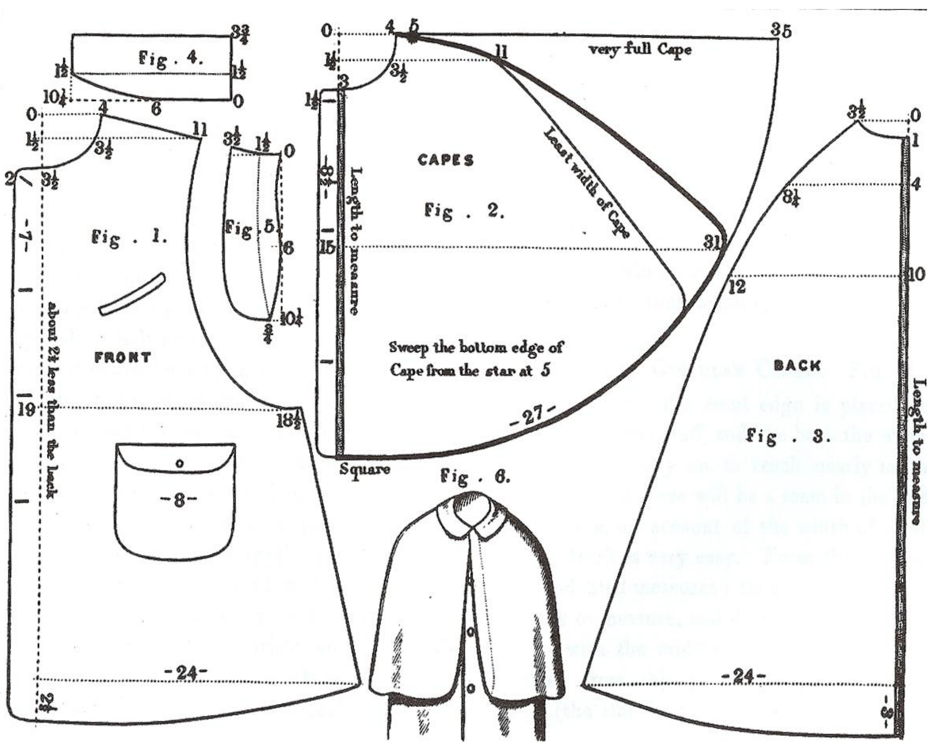


Figure 4.8 Pattern of cape

(http://www.askandyaboutclothes.com/forum/showthread.php?65084-all-kinds-of-overcoats-past-and-present-(with-illustrations-). Retrieved October 1, 2014)

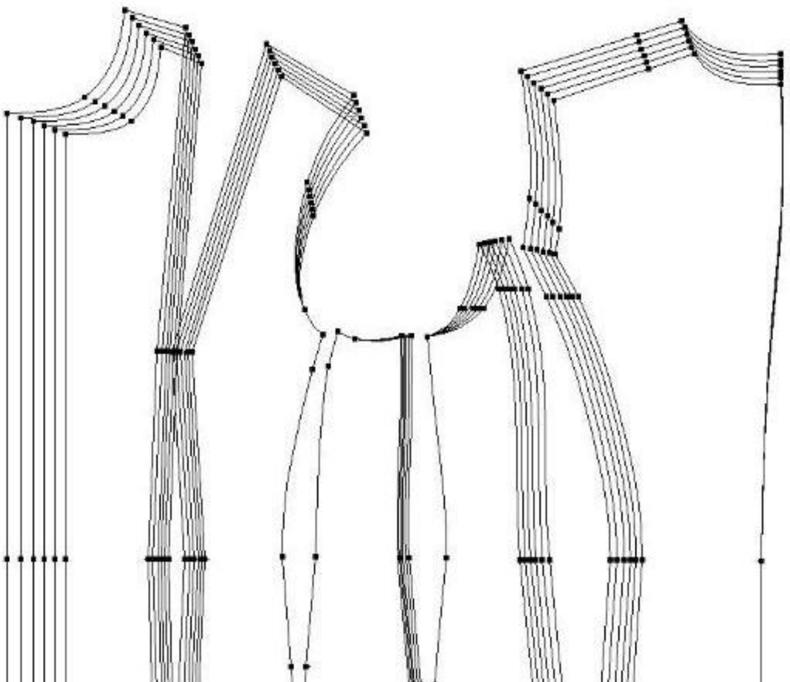


Figure 4.9 Garment grading

(http://free-fashion-coach.blogspot.ca/2011_05_01_archive.html. Retrieved October 1, 2014)

4.2.5 Rational design of apparel products

In general design theory and methodology, there is a theory called Axiomatic Design Theory (ADT) (Suh, 2001). Two salient features of ADT (i.e., coupling and redundancy) are found useful to apparel design. Coupling in ADT says: if a design has several requirements, then (1) these requirements must be kept as independent to one another and (2) design parameters that satisfy the requirements must maintain the independency among the requirements. This is summarized in Axiom 1 of ADT (Suh, 2001). The implication of Axiom 1 of ADT to apparel design is that for apparel design, it is likely that the functional requirement and/or ergonomic requirement may conflict with the affective requirement. This means that Axiom 1 may likely be violated across the requirement domain of utility and that of affect in apparel design. However, the conflict dependency should be made explicit in apparel design, as this information will be very useful to the resolution of this kind of conflicts in a high degree of rationality. Redundancy in ADT says: design is redundant when two or more design parameters are defined to satisfy one requirement. While for functional products, introducing redundancy in design makes sense to improve the reliability of products, for apparel design, redundancy should be avoided because there is no much sense to the reliability of an apparel product. Another important reason is that redundant design may incur new conflicts between the utility and affect, as two design parameters may function the same but have different affective responses, and putting them together, a contradictory affective response may be created.

To facilitate the use of the above knowledge in apparel design, two design rules for apparel design are coined as follows:

Design rule 1 (apparel): dependency or coupling of the requirements across the requirement domain of utility (function and ergonomics) and that of affect is allowed but needs to be explicitly expressed in a design system and known to designer or design team.

Design rule 2 (apparel): redundancy in terms of function in apparel design should be removed. It is noted that redundancy across the category of function or ergonomics and the category of affect implies dependency between an entry in the category function or ergonomic requirement and an entry in the category of the affect, which is allowed according to Design Rule 1.

4.3 Illustration

The SADP in this thesis is supposed to be applicable to different types of apparel. This section is intended to illustrate how to apply the SADP to the design of a gown (a type of apparel). The design problem can be stated as: to design a Chinese actress's gown, which is expected to be worn in a red carpet awards ceremony, to exhibit the following affective attributes: (1) representing Chinese culture, (2) conveying a sense of the feminine, (3) appearing slim and tall, (4) feeling comfortable, and (5) conveying a sense of the nobility.

4.3.1 Design specification development

According to the problem statement, the customer requirements list is set up as shown in Table 4.1, where the first column is the space for marking any possible changes, the middle column includes the requirements and whether they are demands or wishes from the customers, and the right column is the issuing date of the table, and the department or person who are responsible for the requirements of the second column.

Table 4.1 Requirements list for a Chinese actress's gown

	Requirements list for a Chinese actress's gown			Issued on 18/12/2013
Changes	D (Demands) W (Wishes)	Requirements		Responsible
	D	1	Chinese culture	
	D	2	Sense of the feminine	
	D	3	Slim and tall body shape	
	D	4	Comfort	
	D	5	Sense of the nobility	
	D	6	Maximum cost $3000	
	W	7	Harmonious	
	W	8	Conceptual design (1 month)	
	W	9	Embodiment design (2 month)	
	D	10	Detail design (3 month)	

4.3.2 Conceptual design

Step 1: Establishing the requirement structure

The overall requirement and sub-requirement generated from the first phase result in the requirement structures, as shown in Table 4.2. In Table 4.2, the left column is about the overall function and the right column is about the sub-functions. All three categories of requirements, functional, ergonomic, and affective, are included in Table 4.2.

Table 4.2 Requirement structures of the Chinese actress's gown

Overall requirement	Sub-requirement
Represent Chinese culture	Contain Chinese design elements
	Contain Chinese traditions
Show sense of feminine	Reduce visual size of waist
	Highlight the hip
	Highlight the breast
Look slim and tall	Look slim
	Look tall
Feel comfortable	Move easily
	Feel physical comfortable

Step 2: Searching for principle

Principles for the sub-requirements are developed (Table 4.3).

Step 3: Combining the principles into the working structure

Principles (or ADPs for short at the conceptual design phase) are combined into the one called working structure (Pahl et al., 2007). The working structure can be of many, and each of working structure is called variant. One variant or solution (in a general sense) is selected from Table 4.3 and it is shown in Table 4.4. In Table 4.4, the "sub-requirement" column represents the requirements (function, ergonomics, and aesthetics) in the requirement decomposition hierarchy, and the "solution" row represents the solutions to the requirements. By picking up a particular row (e.g., row 1) in the "sub-requirement" column and a particular column (e.g., column 1) in the "solution" column, the cell in the table contains a particular variant or solution to a particular sub-requirement. For instance, “Combination 2-1” refers to the solution 2 (Modern) in terms of sub-requirement 1 (Contain Chinese traditions).

Table 4.3 Principles for the sub-requirements of Chinese actress’s gown

Sub-Requirement	Solution 1	Solution 2	Solution 3
1 Contain Chinese design elements	1-1 Tradition	2-1 Modern	
2 Contain Chinese traditions	1-2 Power	2-2 Respect	3-2 Conservative
3 Reduce visual size of waist	1-3 Reduction of the real waist size	2-3 Application of visual illusion technology	
4 Highlight the hip	1-4 Decoration in the hip	2-4 Curve of the hip	
5 Highlight the breast	1-5 Decoration in the breast	2-5 Material size reduction in the breast area	
6 Look slim	1-6 Application of visual illusion technology		
7 Look tall	1-7 Application of visual illusion technology		
8 Move easily	1-8 Less constraint in the joints		
9 Feel physical comfortable	1-9 Good thermal conductive material	2-9 Good moisture penetrable material	3-9 Fabric affinity

Table 4.4 Elimination and elaboration of solutions

Sub-Requirement	Solution 1	Solution 2	Solution 3
1 Contain Chinese design elements	1-1 Tradition	~~2-1 Modern~~	
2 Contain Chinese traditions	1-2 Power	~~2-2 Respect~~	~~3-2 Conservative~~
3 Reduce visual size of waist	1-3 Reduction of the real waist size	~~2-3 Application of visual illusion technology~~	
4 Highlight the hip	~~1-4 Decoration in the hip~~	2-4 Curve of the hip	
5 Highlight the breast	~~1-5 Decoration in the breast~~	2-5 Material size reduction in the breast area	
6 Look slim	1-6 Application of visual illusion technology		
7 Look tall	1-7 Application of visual illusion technology		
8 Move easily	1-8 Less constraint in the joints		
9 Feel physical comfortable	1-9 Good thermal conductive material	~~2-9 Good moisture penetrable material~~	~~3-9 Fabric affinity~~

Combination 2-1: few of the Chinese elements

Combination 2-2, 3-2: too weak to represent Chinese traditional culture

Combination 2-3, 1-4, 1-5: cannot show the feminine properly

Combination 2-9, 3-9: not that important compared with combination 1-9

The method for generating other variants is the same as the aforementioned one. Note that with the enabler of generating and recording different variants of solutions in SADP, the design process becomes open-ended as well as iterative. Such a process thus supports the open-ended feature because there is more than one solution, and such a process supports the iteration feature because the design process can go back to pick up a different variant other than the previous one. Further, the introduction of the design phase concept allows design iteration to cross over different design phases. For example, at the conceptual design, there may be two variants. Which one is the best cannot be resolved at the conceptual design phase per se but resolved at the embodiment design phase. In this case, the design first goes from the conceptual design to the embodiment design, and then goes back to the conceptual design to resolve the pending issue at the conceptual design phase.

4.3.3 Embodiment design

In this phase, the spatial layout of the Chinese actress's gown will be carried out. The layout will be illustrated by the color, material, texture, and so on.

Step 1: Identifying the overall constraint for the embodiment design

The following items are generated from the requirements list:

(1) Determining dimension:
  Ease of gown ≈ 2cm
  17 cm ≤chest − waist ≤22 cm
  25 cm ≤ hip – waist ≤ 34 cm

(2) Determining material:
  Natural and stretch fiber

Step 2: Determining the design parameter

The design parameters that determine the embodiment are listed in Table 4.5. At the end of this step, material type, color and texture of the material of the gown have been determined.

Step 3: Developing the preliminary layout

The preliminary layout with its material, color and basic silhouette is drawn to be an illustration (Figure 4.10).

4.3.4 Detail design

At this design phase, a technical pack, a pattern and a grading of the gown are completed (RE: Figure 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, and 4.9). For example, the detailed size of the gown (e.g. shoulder and hip) is determined (RE: Figure 4.4), and the grading size is determined (RE: Figure 4.9). It should be noted that before the pattern generation, a design can still go back in order to address any issue, which means that the SADP supports the iterative design process.

Table 4.5 Design parameter for Chinese actress's gown

Sub-requirement	Design parameter	Characteristics
1 Contain Chinese design elements	Material (brocade with dragon pattern)	Unique Chinese textile
2 Contain Chinese traditions	Color (gold)	Represent nobility
3 Reduce visual size of waist	Size (ease of the waist)	Adjust the space between the waist and the gown
4 Highlight the hip	Size (ease of the hip)	Adjust the curve of hip
5 Highlight the breast	Material (cover area)	Hide the breast
6 Look slim	Proportion (width and length proportion)	Adjust the proportion between width and length of the gown
7 Look tall	Proportion (upper and lower gown proportion)	Adjust the proportion between upper gown and lower gown
8 Move easily	Material (stretch)	Reduce physical constrains
9 Feel physical comfortable	Material (Nature- fiber)	Better thermal conductivity

Figure 4.10 Illustrations for Chinese actress's gown

4.4 Concluding remarks

In this chapter, a new apparel design process was proposed by applying the systematic design approach to general product design in the engineering design domain. The new apparel design process has four phases, namely, design specification development, conceptual design, embodiment design, and detail design. The traditional apparel design process was transformed to a systematic one called the SADP. The SADP has the following features: (1) the steps in the design process are logical and fine-grained, and (2) the appropriate information repositories are associated with the steps. Consequently, with these two features, the nature of iteration and open-endedness of design is possessed by SADP. It is worth mentioning that a design process with this nature is conducive to brainstorming and team design practice such that the quality of design can be improved.

CHAPTER 5 MODELING OF HUMAN AFFECT

In any product design, the first and most important thing to determine is the customer requirement. For a product such as apparel, the customer requirement includes not only the function and usability of the product but also the affect or emotion the product creates. The quantification of the function and usability requirement of the product is readily available; however, the quantification of a customer's affective requirement for a product is still a pending issue (Zhao, 2015).

This chapter presents a work that is aimed at developing a procedure to compile a list of adjectives that represent the customer's affect in a specific domain, the apparel domain in this case. First of all, Section 5.1 presents a general procedure for compiling affective words for product design by employing web-mining technology and expert elicitation technique. Section 5.2 presents the application of this general procedure in the apparel domain by compiling words that represent how wearers feel about the apparel. The affective words are used for building the relationship between human affect and apparel design parameters in Chapter 6. Section 5.3 introduces an example to validate the compiled affective words. The conclusion is given in Section 5.4. Part of the research described here appears in the following paper: Zhao, Y., Montazeri, A., Wang, C., & Zhang, W.J., On development of methods for expressing customer affective response for apparel products, Proc. CAD'15, London, UK, 2015, 315-320.

5.1 The procedure to compile affective words

Affective words are mainly adjectives and nouns. Without loss of generality, only adjectives are considered in the present study. There are two main steps for collecting affective words: search and evaluation. A technique called web mining is employed to compile affective words (Etzioni, 1996). The web-mining technique is in essence to search the Web to discover knowledge for a particular domain of activity or event (apparel design in this case) using the computer rather than manually searching (Etzioni, 1996). There are three categories of knowledge: content, structure, and use/purpose/context (Borges & Levene, 2000; Madria et al., 1999). The details of the web-mining technique were discussed in Chapter 2. The following is a procedure based on web mining as well as a proprietary tool (Wang, 2008). This procedure has six steps.

Step 1: Experimenter identifies the source of data (i.e. website).

Step 2: Experimenter collects the articles from the source and reformats the articles, preparing for extraction of adjectives.

This step is achieved with an in-house developed tool called Clipboard Sniffer (appendix C), and it is developed by a former member of the research group. The input to the tool is the content of a particular article, and the output is the content that is formatted into a plain text, preparing for the word screen process (the next step).

Step 3: Experimenter extracts adjectives in each medium.

This is achieved with an in-house developed tool called Adjective Extractor (accessed from http://homepage.usask.ca/~yuz703/) (appendix D). The input to this tool is a collection of articles that are in a plain-text format, and the output is the adjectives. The extraction process is terminated and turned to the next step once an increase of the number of articles does not result in any increase of the number of adjectives.

Step 4: Experimenter refines the list of words based on the statistics of words.

There are two statistics that can be found with an in-house developed tool called TF-DF Generator, which processes a list of documents, say document 1, 2, and to n. Details of TF-DF can be found in appendix E. The first statistic is the number of times a term appears in document *i*. This statistic is denoted as TF (term frequency) (Ramos, 2003). The second statistic is the number of documents in which a term appears. This statistic is denoted at DF (document frequency) (Rajaraman & Ullman, 2011). In this research, TF is not used, as it is believed that the number of appearances of a particular term in one document does not add value to the popularity of this term. However, DF is, indeed, a measure of the popularity of a term, as each document is different and represents a unique context for the term.

Step 5: Experimenter conducts a syntactical-based analysis of the collected adjectives with the goal of removing any abnormal adjective, leading to a set of syntactically clean adjectives.

Adjectives with an extremely high or a low DF are regarded as abnormal adjectives, and they are removed from the list. Adjectives with an extremely high DF have a high chance of not being specific to a particular domain, i.e. apparel domain in the present study. Adjectives with an extremely low DF are suspect, and therefore removed.

Step 6: Experimenter conducts a semantic-based analysis of the set of adjectives obtained from Step 5 with the goal of reaching a set of adjectives that describe the customer's affective requirements in a specific domain.

A number of experts are asked to make two decisions. The first decision is whether adjectives make sense in the apparel domain. The second decision is which adjectives have similar meaning, that is, to develop a list of synonyms, say $\{S_1, S_2, \ldots, S_n\}$. The synonyms list is intended for developing a user-friendly interface of CADOA by offering the possibility that different users may prefer to use different words that express a similar meaning.

For each decision, a consensus needs to be formed. The first decision is made by using the probability distribution aggregation technique (Liu et al., 2012). This has been done by the following procedure. First, a 5-level Likert scale is used, in which, "1" refers to the least relevant (of a particular word) to the domain, and "5" refers to the most relevant. Second, for each adjective, all the experts rate it with the 5-level Likert scale. Third, an aggregated rate for the adjective is formed. In appendix F, there is a brief description of the aggregation process, as well as the code for running it. By running the foregoing procedure, a rate for each adjective is created. An adjective with low rate, namely the rate lower than a threshold (determined empirically), is removed from the list of affective adjectives for the product design. For the convenience of later discussions, this list is called Affective Adjectives List (AAL).

For the second decision, the following process is proposed and exercised in the present work. Step A: for each adjective, say word *i*, the experts examine all the other words in the AAL to see if they are similar in meaning to word *i*; this will lead to a list of adjectives that have a similar meaning to word *i*, denoted as Word Synonyms List (WSL). Step B: a simple majority vote on WSL by the experts eventually determines WSL. That is, for a particular word, say x in AAL, a word y in AAL is found. If majority of the experts votes y for its similarity with x, then y will be in the WSL list for x. Note that the majority is defined as the half number of experts or more than the half number of experts in this study. The outcome of the foregoing procedure is the set WSL_i (i=1, 2,…, m, where m is the total number of adjectives in AAL).

5.2 The application to apparel product design

The application domain is apparel. The following is presented to obtain the adjectives that express the consumer affective requirement for apparel products based on the proposed procedure described in Section 5.1.1. That is, the six steps are run to generate an AAL and a WSL for apparel design.

By following Step 1, 13 websites (Table 5.1) were selected as the sources for affective words. By following Step 2, over 400 articles were collected from the aforementioned websites. These articles can be found on the website http://homepage.usask.ca/~yuz703/. Note that these articles are in a plain-text format. By following Step 3, Figure 5.1 was generated, from which it can be seen that the increase in the number of articles does not increase the number of adjectives. The process of the article collection was terminated at the point that 446 articles were examined. As a result, 1164 adjectives (accessed from http://homepage.usask.ca/~yuz703/) were obtained. By following Step 4 and Step 5, the threshold for low DF was 1, and there were 492 adjectives with DF=1. By removing the adjectives with DF=1, 672 adjectives were obtained (accessed from http://homepage.usask.ca/~yuz703/).

Table 5.1 Web sources

Name of Website	URL
Glamour	http://www.glamour.com
People Style Watch	http://www.people.com/people/
Teen Vogue	http://www.teenvogue.com/
Loop	http://www.theloop.ca/
Seventeen	http://www.seventeen.com/
Marie Claire	http://www.marieclaire.com/
Redbook	http://www.redbookmag.com/
Fashion	http://www.fashionmagazine.com/
Elle	http://www.ellecanada.com/
Loulou	http://en.louloumagazine.com/
Cliché	http://www.clichemag.com/
Australian Fashion Review Blog	http://www.fashionreview.com.au/
My Fashion Review Express Yourself	http://myfashionreview.co.uk/

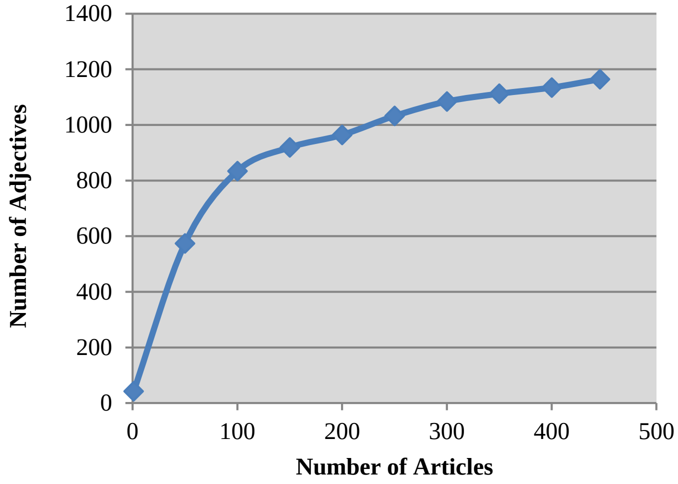


Figure 5.1 The relationship between the number of adjectives and number of articles

The removal of adjectives which are not specific to the apparel domain is determined by means of the so-called high DF. In this case, the adjectives with the high DF were determined by the following approach. First, a proprietary collection of adjectives that have a high DF was created, which was developed by a general study of adjectives (Wang, 2008). In the aforementioned collection, there were adjectives with their DF ranging from 1 to 34141. The adjectives with their DF greater than 10000 were inspected and discovered that they were the category of the so-called general adjectives and they should be removed from the list. Specifically, the list of these general adjectives can be found from the http://homepage.usask.ca/~yuz703/. Let us call this list “general word reference (GWR).” Second, the obtained list (672 adjectives) and GWR list were compared, and the adjectives in the obtained list that also appeared in the GWR list with high DF were thus removed. It is noted that the removed adjectives were too general to make sense to apparel (e.g., word ‘nice’ is too general to be kept in the list). Consequently, 49 adjectives were removed, which resulted in the list of 623 adjectives (accessed from http://homepage.usask.ca/~yuz703/), and this resulting list makes sense for apparel design.

In running Step 6, for the first decision, 6 apparel experts were recruited in the study to rank the 623 adjectives in the list. The profiles of the experts include: (1) their careers are related to apparel, such as fashion designer, fashion photographer, runway model, or stylist; (2) their ages are between 19 and 25; (3) there is a mix of genders; (4) they are Canadian residents. The aggregated ranking for each adjective was obtained by applying a particular aggregation process (accessed from http://homepage.usask.ca/~yuz703/). The adjectives with the aggregated ranking less than 4 were removed (appendix F). Consequently, 60 adjectives could be obtained and they were the AAL for apparel design. For the second decision, the 30 WSL groups (Table 5.2) were obtained by the simple majority vote from the experts (see Section 5.1 for the simple majority vote procedure).

Table 5.2 WSL for apparel design

Group	Adjectives	Group	Adjectives
1	classic	16	soft, pastel
2	feminine	17	delicate, detailed,
3	edge, artistic	18	hot, sexy
4	flattering, fancy, chic, stylish, dressy	19	cute, adorable
5	uniform, professional	20	sophisticated
6	relaxed, casual	21	comfortable
7	inspiring, asymmetrical, futuristic, unpredictable, personal, unique	22	sporty, athletic
8	vibrant, exciting	23	practical
9	dramatic	24	slouchy
10	minimal, understated, simple, light, mini, basic	25	youthful
11	bohemian	26	glamorous, gorgeous, brilliant, stunning
12	unconventional	27	androgynous, natural
13	outside, playful	28	exclusive
14	romantic	29	fashionable, trendy
15	boyish	30	traditional, conservative

5.3 Validation of affective words

The validation of the compiled AAL and WSL collection was performed with the following experiment. The general idea of the experiment was to observe subjects on their affective expression for some controlled apparel and to see if the words in their expressions appear in the AAL. Following this idea, 16 subjects were selected. The profiles of the subjects include: (1) different careers (including jobless); (2) their ages are between 19 and 70; (3) there is a mix of genders; (4) Canadian residents. Four apparel products were used, and they are apparel products

(1) to be worn by a person who is going to give a presentation or seminar (Figure 5.2(a)); (2) to be worn to go to a night club (Figure 5.2(b)); (3) to be worn for a workout (e.g., running) in the gym (Figure 5.2(c)); and (4) to be worn by a person who is going to attend a banquet (Figure 5.2(d)). The 16 subjects were divided into 4 groups with each using a different apparel product. The subjects were pre-trained before the experiment started to get familiar with using adjectives to describe their feelings about the product with its usage scenario.

(a) (b)

(c) (d)

Figure 5.2 Four scenarios

(a) presentation (https://www.edcast.org/learn/presentation-skills-give-a-great-team-presentation-fall-2015. Retrieved February 20, 2015) (b) night club (http://jordandetmers.com/2014/06/25/the-psychology-of-a-nightclub/. Retrieved February 20, 2015) (c) workout (http://www.wallpaperseries.com/more/gym-workout-wallpaper.html. Retrieved February 20, 2015) (d) banquet (https://www.securecms.com/icassp2006/specialevents.asp. Retrieved February 20, 2015)

The experimenter held a conversation with each subject on a corresponding apparel product and solicited their affective opinions. The conversation was recorded. After that, the experimenter checked the affective words in the conversation with the AAL to see if the words are in the AAL. The words that hit the AAL were further checked with the WSL. The recorded voice conversations are accessible on http://homepage.usask.ca/~yuz703/.

The words used by each subject are listed in Table 5.3. There were, in total, 93 adjectives used by the subjects during the conversation, and 64 among them were in the AAL. Thus, 68.817% words used by the subjects were in the AAL, which means that mostly, the words in the AAL would be used by a customer in affective design for apparel products. Note that those adjectives used by the subject that were not in the AAL are quite similar to the adjectives in AAL, e.g. energetic (similar to exciting), distinctive (similar to unique), formal (similar to professional), and attractive (similar to flattering), etc. Thus, the AAL is valid and can be used in affective design practice for apparel products. Further, for a single scenario, similar adjectives were found; for example, for the gym scenario, stylish and chic (similar), sporty and athletic (similar); for the presentation scenario, simple and basic (similar), exciting and vibrant (similar), traditional and conservative (similar); for the night club scenario, sexy and hot (similar), fancy and stylish (similar); for the banquet scenario, fashionable and trendy (similar), chic, stunning and stylish (similar). This result showed that WSL makes sense.

Table 5.3 Adjectives used in the conversation for four scenarios

Scenario	Participant	Adjectives used in the conversation
Apparel for giving an presentation	1	soft, fit, safe, stylish, chic, fashionable, comfortable, professional, sporty, athletic
	2	soft, comfortable, practical, stylish, vibrant, tight, lose, quick
	3	practical, good, pretty, stylish, comfortable
	4	sporty, soft, comfortable, practical, financial
Apparel for going to a night club	5	professional, simple, light, casual, classic, traditional
	6	formal, casual, professional, classic, fancy, basic
	7	feminine, comfortable, beautiful, exciting, vibrant
	8	comfortable, conservative, attractive, neat, fancy
Apparel for the workout in the gym	9	sexy, feminine, comfortable, unique, glamorous
	10	fancy, hot, tight, comfortable, fun, attractive
	11	fun, energetic, stylish, comfortable, attractive, feminine, modest, conservative, tight, dark, mysterious
	12	hot, fashionable, glamorous, attractive, comfortable
Apparel for attending a banquet	13	classic, comfortable, fashionable, stylish, dignified, distinctive, proper
	14	classic, feminine, fashionable, trendy, comfortable, chic, stylish, detailed, glamorous
	15	stunning, flatting, fancy, comfortable, unique, pretty
	16	unique, inspiring, comfortable, awkward, formal

5.4 Concluding remarks

In this chapter, a new procedure for compiling affective words in the apparel domain was presented by employing web-mining technology and expert opinion aggregation technique. A collection of 60 affective words has been obtained. These words were further grouped into 30 groups due to their similar meaning. The validation experiment was carried out, which shows that almost 69% of the affective words were directly used by the subjects in the experiment to describe their affects in four scenarios. All the other words that were not found in the collection have similar words in the list. The future work is warranted to study whether these words should be included in the collection or why these words are not included in the current collection. It is noted that the affective words collection is the most important step for affective design to become possible. The next chapter will demonstrate the possibility of finding a relationship between the affective word and design parameter in the apparel design domain, and this relationship will allow us to find design parameters to satisfy affective words.

CHAPTER 6 ESTABILISHING THE RELATIONSHIP FROM AFFECTIVE WORDS TO DESIGN PARAMETERS

The goal of this chapter is to establish a mapping from the affective words to the apparel design parameters (ADPs). Section 6.1 is a definition of the ADPs along with their domains. In Section 6.2, some of the affective words compiled from Chapter 5 are defined along with their domains. Section 6.3 presents details of the modeling. Section 6.4 is model verification. The conclusion is given in Section 6.5. Note that this mapping is also called AW (affective word) (or FW (feeling word))-TO-DP (or ADP) mapping hereafter in this thesis. Part of the work described in this chapter appears in the following publication: Zhao, Y., Sun, J., Gupta, M. M., Moody, W., Laverty, W.H., & Zhang, W. J., 2015, On Mapping from Affective Words to Design Parameters for Apparel Design. Textile Research Journal. Submitted.

6.1 Definition of apparel design parameters

In Section 2.4.2, the ADPs of apparel were discussed. ADPs that are solely relevant to the affective aspect are color, material, and silhouette (Table 6.1). The domains for these ADPs are defined as value ranges; for instance, the domain of the color ADP is hue valued from 0 to 355, saturation valued from 0 to 255, and value valued from 0 to 255. However, only three levels (low level, medium level and high level) of values for each ADP were considered in this study due to the limited resource for experiments. For example, the three levels of the ADP of hue are: 60 as low level, 180 as medium level and 300 as high level. Domains of the other ADPs are given in appendix G. It is to be noted that those other ADPs particularly related to the geometry of an apparel is not considered in this thesis, because they are more associated with the function and ergonomic aspects of apparel.

Table 6.1 Summary of ADPs

Three general factors	Specified ADPs
Color	Hue, saturation, value
Material	Stretch, bending, buckling, damping, density
Silhouette	Shoulder, waist, hem

6.2 Definition of affective words

In Chapter 5, a complete set of affective words was obtained (i.e., AAL). Only a portion of them were used to develop their relationship with ADPs without loss of generality (Table 6.2). Domains of these words refer to the five-level Likert scale; for instance, for the word "casual," its domain is from 1 to 5, representing strongly disagree, disagree, neutral, agree, and strongly agree.

Table 6.2 Thirty affective words used in investigating the relationship between human's affect and ADPs

androgynous	bohemian	boyish	casual	classic
comfortable	conservative	delicate	dramatic	cute
edgy	exclusive	feminine	glamorous	playful
practical	professional	romantic	sexy	slouchy
soft	sophisticated	sporty	stylish	trendy
unconventional	understated	unique	vibrant	youthful

6.3 Model building for mapping from AW to ADP

The general methodology has the following elements. First, a picture is shown of a runway model wearing an article of apparel with all three categories of design parameters (namely, color, material, and silhouette), with the affective words from the AAL (Table 6.2) developed in Chapter 5, describing the displayed apparel to the subject. Second, the subject ranks the appropriate affective words he or she feels after viewing the runway model's performance according to the five-level Likert scale. Third, the pair of "values," namely <ADP-value, AW-value> is created, and subsequently, a number of such pairs are created, which is then referred to as the training data. Fourth, a learning process (e.g., Neural Networks technique) is applied to create the AW-TO-ADP mapping based on the training data.

6.3.1 Experimental design for collecting raw data

Subject

There were 100 subjects selected. The selection criteria are: (1) they must be Canadian residents and (2) their age is in the range of 18 to 35. This experiment was approved by the Behavioral Research Ethics in University of Saskatchewan (appendix H).

Questionnaire

There are 27 apparel scenarios that were presented to the subjects. Each scenario contains: (1) a simulated runway model wearing an article of apparel, (2) the list of affective words in the AAL developed from Chapter 5, and (3) the five-level Likert scale for each affective word. Figure 6.1 shows an example of the apparel scenario generated by a computer system called Marvelous Designer (MD). The complete list can be found from https://fluidsurveys.usask.ca/s/rainzhao/. Six scenarios were randomly presented to each subject in order to avoid any bias in terms of the familiarity factor and to collect a sufficient number of samples for a high statistic power.

The reason to have 27 scenarios is related to the total number of combinations or instances of the ADPs. From Table 6.3, it can be seen that there are 11 ADPs called factors (in the context of the statistic experiment). Each ADP factor has three levels (determined with consideration of the number of experiments that need to be conducted). The total number of experiments would then be 3^{11}-1, which would be impossible to carry out. However, by applying the orthogonal array technique (IMB SPSS, 2015), the number of experiments reduced to 27. Table 6.3 shows the full list of instances of the ADPs. The values of the ADP are listed in appendix G.

The scenarios were released on the platform called "FluidSurveys" platform online for approximately two months (from 01/08/2014 to 29/09/2014): https://fluidsurveys.usask.ca/s/rainzhao/. During that period of time, subjects were asked to access the website to watch the scenarios and to respond to the questions. At the end of the two-month period, 100 instances of scenario shows were performed and 600 samples were collected.

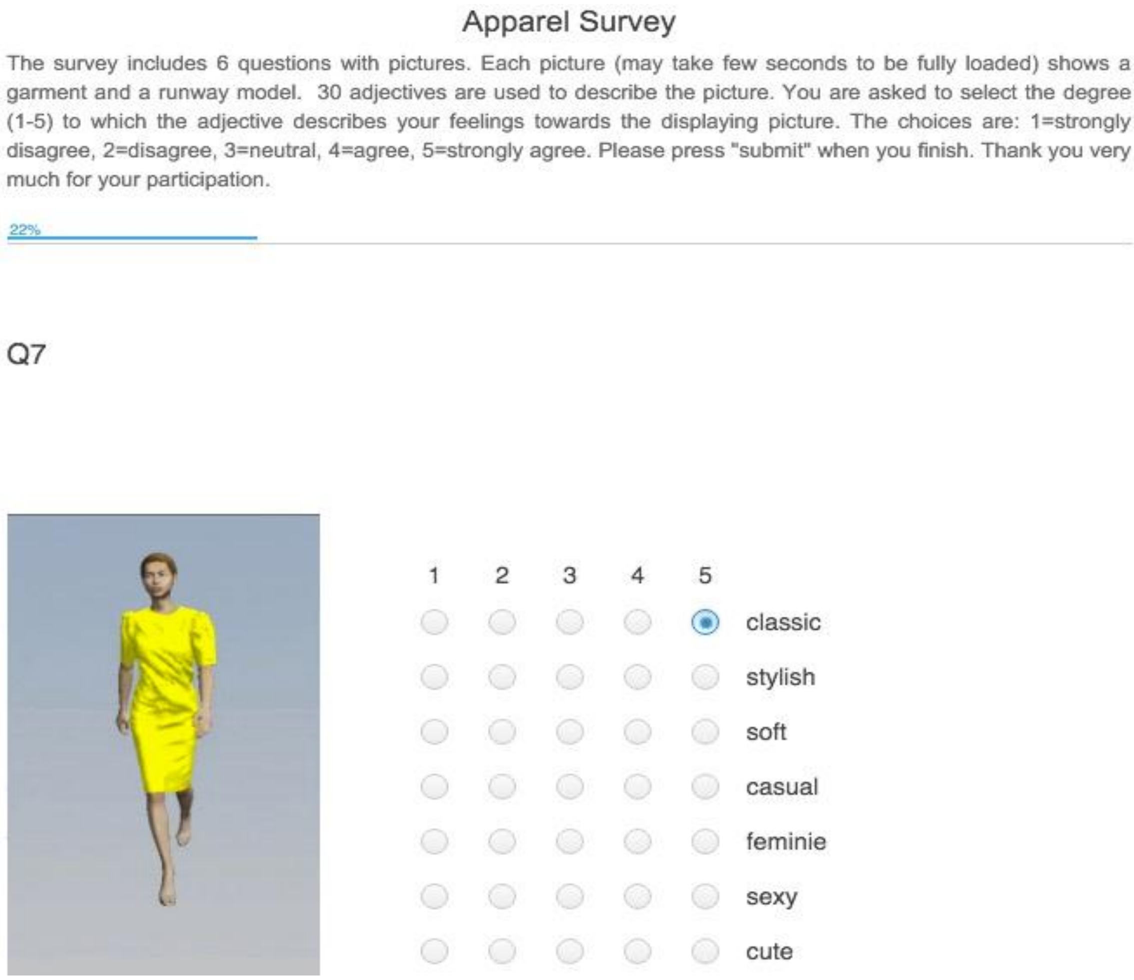


Figure 6.1 An example of a typical question presented to the subjects during the survey

6.3.2 Data analysis and model development

6.3.2.1 Data pre-processing

Before performing data analysis, the data collected required some cleaning and the outliers were removed from the data. The following data were removed.

(1) The same Likert item is given to all or most of the affective words (e.g., “2” is given to all affective words).
(2) The difference in the Likert items to all affective words is very small (e.g., “2” or “3” is given to all affective words).
(3) Incomplete data sets (some items are missing).

As a result, 565 data out of 600 data were kept for data analysis.

Table 6.3 The 27 possible combinations of the ADPs

Combination	Hue	Saturation	Value	Stretch	Bending	Buckling	Damping	Density	Shoulder	Waist	Hem
1	60	42	42	64	15	28	1	27	35	66	90
2	60	42	42	64	107	63	5	38	38	73	200
3	60	42	42	64	180	99	10	50	41	80	310
4	60	128	128	105	15	28	1	38	38	73	310
5	60	128	128	105	107	63	5	50	41	80	90
6	60	128	128	105	180	99	10	27	35	66	200
7	60	213	213	147	15	28	1	50	41	80	200
8	60	213	213	147	107	63	5	27	35	66	310
9	60	213	213	147	180	99	10	38	38	73	90
10	180	42	128	147	15	63	10	27	38	80	90
11	180	42	128	147	107	99	1	38	41	66	200
12	180	42	128	147	180	28	5	50	35	73	310
13	180	128	213	64	15	63	10	27	41	66	310
14	180	128	213	64	107	99	1	38	35	73	90
15	180	128	213	64	180	28	5	27	38	80	200
16	180	213	42	105	15	63	10	50	35	73	200
17	180	213	42	105	107	99	1	27	38	80	310
18	180	213	42	105	180	28	5	38	41	66	90
19	300	42	213	105	15	99	5	27	41	73	90
20	300	42	213	105	107	28	10	38	35	80	200
21	300	42	213	105	180	63	1	50	38	66	310
22	300	128	42	147	15	99	5	38	35	80	310

Combination	Hue	Saturation	Value	Stretch	Bending	Buckling	Damping	Density	Shoulder	Waist	Hem
23	300	128	42	147	107	28	10	50	38	66	90
24	300	128	42	147	180	63	1	27	41	73	200
25	300	213	128	64	15	99	5	50	38	66	200
26	300	213	128	64	107	28	10	27	41	73	310
27	300	213	128	64	180	63	1	38	35	80	90

6.3.2.2Neural network architecture for the AW-TO-ADP mapping

Neural Networks (NNs) is a technique used to describe the multiple-input and multiple-output (MIMO) relation. NNs consists of a set of neurons (nodes) with a set of weighted edges that connect the neurons (nodes), a set of inputs and a set of outputs (Figure 6.2). These components are configured into a special topology (Figure 6.2) in such a way that (1) a list of inputs and a particular input are called input node, (2) a list of outputs and a particular output are called output node, (3) between the input and output are several neuron layers (i.e., layers that contain several neurons) and a particular neuron is called neuron node, (4) nodes in a layer do not connect with each other, but connect with nodes in all nodes in the subsequent layer, (5) within each neuron there is an activated function such that a neuron node acts like a system with the behavior represented by the activated function, (6) the input to a particular neuron system in a particular neuron layer is the linear weighted (denoted as w) sum of all the outputs of the neurons in the preceding layer plus a bias (denoted as b), and (7) all the inputs are linear weight sum to be an input to the neuron (or activated function), while the outputs are connected to the neurons in the last layer (or the output layer).

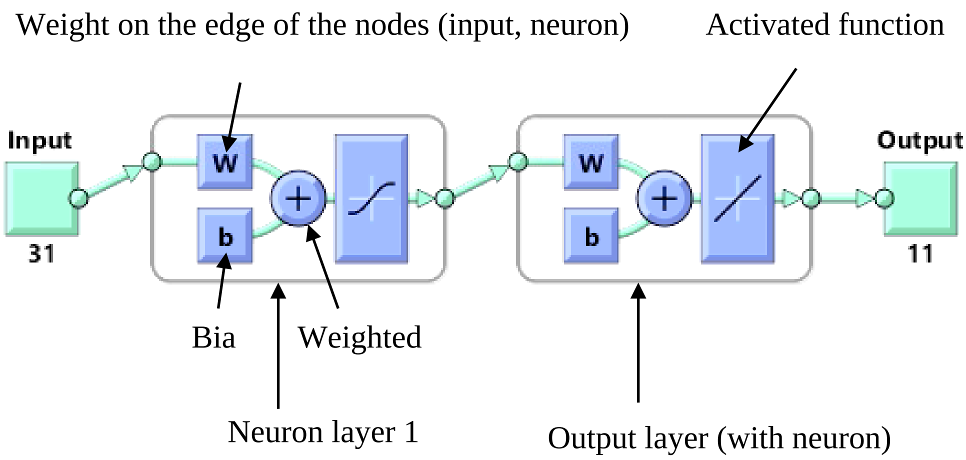
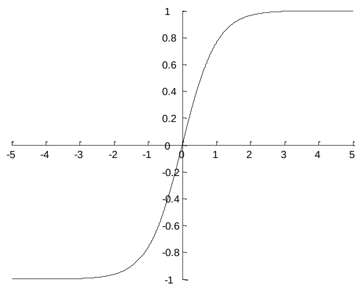
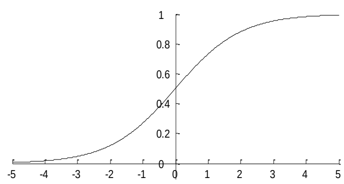
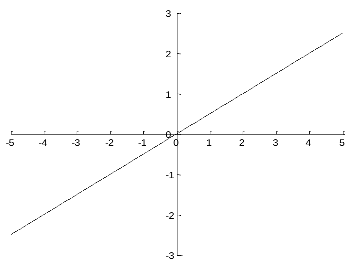


Figure 6.2 The generic architecture of NNs

To design a NNs model for a particular problem (e.g., the AW-TO-ADP mapping), the above components must be determined, that is in particular (i) the number of neuron layers, (i) the number of neurons in each neuron layer, (iii) the activated function, and (iv) the weight. The way of determining the foregoing components is empirical-based, except for (iv) the weight, which is principle-based. The general principle of determining the weights is to determine the weight such that the behavior of a NNs model under construction most closely mimics the behavior of a problem system under modeling (e.g., the AW-TO-ADP mapping). The process of determining the weight is called training or learning in the NNs literature (Gupta et al., 2003). A commonly used method to determine the weight is called backpropagation (BP) (Heaton, 2008), and the algorithm for this method is called Levenberg-Marquardt (LM) which is available in Matlab NNs tool box. This study employed the LM algorithm.

Further, the input and output data need to be normalized to avoid disturbances due to different scales of data, and data with normalization often performs better (Sola & Sevilla, 1997). There are mainly three main activated functions, namely, Hyperbolic Tangent Sigmoid (HTS) (or Tansig function), Log Sigmoid (LS) (or Logsig function) and Purlin function (or Linear function) (LF) (Alavala, 2008; Wong, et al., 2003) (Table 6.4). The rule of selecting the activated function in the output layer depends on the value range of outputs. If the value range of output is [0, 1], LS is chosen; if the value range is [-1, 1], HTS is chosen; and LF is suitable for all value ranges.

Table 6.4 Activated function for Neural Networks

Function type	Function Expression	Function Diagram
Hyperbolic Tangent Sigmoid (HTS)	$tansig\ (x) = \frac{2}{1+e^{-2x}} - 1$	
Log Sigmoid (LS)	$logsig(x) = \frac{1}{1+e^{-x}}$	
Linear function (LF)	$LF(x) = mx$	

In this study, both single hidden layer or neuron layer (except the output layer) and two hidden layers or neuron layers (except the output layer) were tried. Note that two hidden layer NNs models are often used for solving nonlinear problems (Lapedes & Farber, 1987). The following design decisions were also made: (1) different numbers of hidden neurons were tried, ranging from 10 to 100; (2) all data sets of the outputs were normalized to [0, 1], and thus LS was applied as the activated function in the output layer; (3) both LS and HTS were applied in the hidden layer(s). The normalization function is:

$$x' = \left|\frac{x - x_{min}}{x_{max} - x_{min}}\right| \quad (6.1)$$

where x_{min} and x_{max} are the minimum and maximum for the input and output data sets. In this study, 70% of the data was used for training, 15% of the data was used for validation and 15% of the data was used for testing. The statistic method of Mean Squared Error (MSE) for test data sets was employed to show the performance of NNs. The mathematical expression of MSE is:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(y_i^{obs} - y_i^{pred}\right)^2 \quad (6.2)$$

where y_i^{obs} is the experimental output as observed, and y_i^{pred} is the predicted or anticipated output obtained from NNs. The smaller the MSE is, the more accurate the model is. R (regression coefficient) was employed to indicate the relationship between y_i^{obs} and y_i^{pred}. If R is close to 1, it indicates that y_i^{pred} is close to y_i^{obs}. In other words, the larger R is (the closer to 1), the better the model predicts the outcome from the data sets. Training R was obtained from the training data sets, while test R was obtained from the testing data sets. The structure of the NNs models is shown in Table 6.5; and the code for conducting the NNs can be accessed from http://homepage.usask.ca/~yuz703/.

The Higher-Order NNs model (Gupta et al., 2003) was also employed to develop the AW-TO-ADP mapping. In the Higher-Order NNs model, the input to a particular neuron of a particular layer is not based on the linear weight sum but is rather the quadratic weight function of all inputs from the preceding layer. Figure 6.3 shows such a NNs model, which is also called Higher-Order Synaptic Operation (HOSO) (Gupta et al., 2003).

Table 6.5 Structure for the NNs model and Higher-Order NNs model

NNs parameters	NNs	Higher-Order NNs
Number of layers	3	3
Number of hidden layers	1 and 2	1
Training algorithm	Levenber-Marquardt BP	Levenber-Marquardt BP
Data normalization	[0, 1]	[0, 1]
Activated function (output layer)	LS	LS
Activated function (hidden layer)	LS and HTS	LS and HTS
Number of neurons	10~100	10~100
Data division	70% for training, 15% for validation and 15% for test	70% for training, 15% for validation and 15% for test
Accuracy evaluation	MSE of test data sets	MSE of test data sets
Performance evaluation	Training R and test R	Training R and test R

As shown in Figure 6.3, HOSO can be of numerous orders. The first order is the conventional linear correlation, which is the same as the conventional NNs. In this study, a second-order HOSO was considered which is called quadratic synaptic operation (QSO) (Gupta & Rao, 1993; Gupta, 2008; Gupta et al., 2010). The *N-th* order HOSO is defined as:

$$v = w_0 x_0 + \sum_{i_1=1}^{n} w_{i_1} x_{i_1} + \sum_{i_1=1}^{n} \sum_{i_2=i_1}^{n} w_{i_1 i_2} x_{i_1} x_{i_2} + \cdots + \sum_{i_1=1}^{n} \sum_{i_2=i_1}^{n} \cdots \sum_{i_N=i_{N-1}}^{n} w_{i_1 i_2 \dots i_N} x_{i_1} x_{i_2} \dots x_{i_N} \quad (6.3)$$

where *w* is the weight, *x* is the input and *v* is sum of the weighted inputs up to the second order.

In this study, the structure of QSO was quite similar to that of the conventional NNs (Table 6.5). The only difference between the structure of the LSO (linear synaptic operation) and the QSO is that the LSO considers one and two hidden layers, while only a single hidden layer is considered in the QSO. The reason is that a single layer QSO is sufficient to solve nonlinear problems, whereas an LSO requires two hidden layers. The code for conducting QSO can be accessed from http://homepage.usask.ca/~yuz703/.

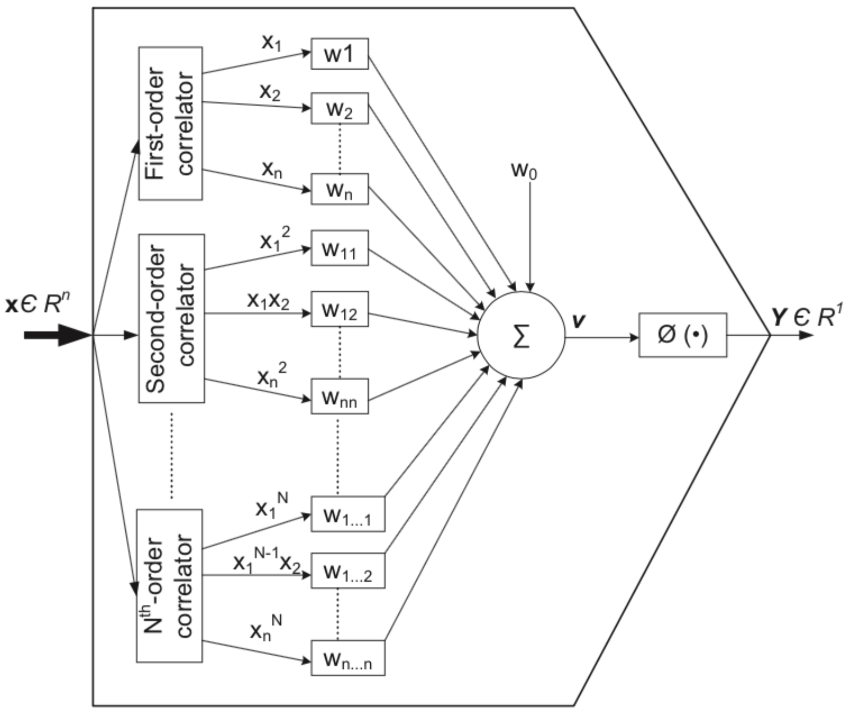


Figure 6.3 A neural unit (neuron) with Higher-Order Synaptic Operation (HOSO) (Gupta et al., 2003)

6.3.2.3 Results

Forty models were built through the LSO, and 20 models were built through the QSO. Figure 6.4 presents a comparison of the MSE for all models. These models were built by QSO-HTS (QSO with HTS as its activated function in the hidden layer), QSO-LS (QSO with LS as its activated function in the hidden layer), LSO-HTS-1 (a single hidden layer LSO with HTS as its activated function in the hidden layer), LSO-LS-1 (a single hidden layer LSO with LS as its activated function in the hidden layer), LSO-HTS-2 (two hidden layers LSO with HTS as its activated function in the hidden layers), and LSO-LS-2 (two hidden layers LSO with LS as its activated function in the hidden layers). It has been found that apart from LSO-HST-1 with 60 neurons and QSO-HTS with 20 neurons, other MSEs are less than 0.05. The smallest one is 0.03164 obtained from LSO-LS-2 with 80 neurons. The details of the MSE for each model are accessed from http://homepage.usask.ca/~yuz703/.

Figure 6.5 shows the comparison of training R among six NNs models. It is found that the number of neurons in the hidden layer(s) has a greater influence on the training R with QSO than with LSO, as the training R of QSO-HTS and QSO-LS fluctuates dramatically as the number of neurons varies. Noted that QSO-HTS with 90 neurons has the highest training R (with 0.92074). The details of the training R for each model can be accessed from http://homepage.usask.ca/~yuz703/.

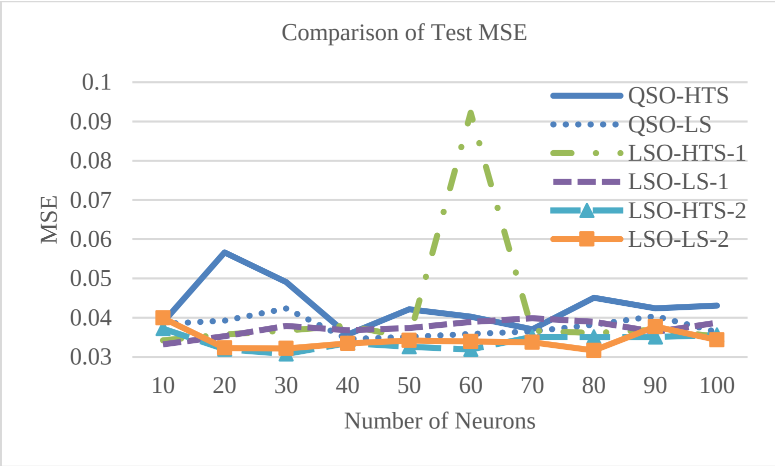


Figure 6.4 MSE comparison

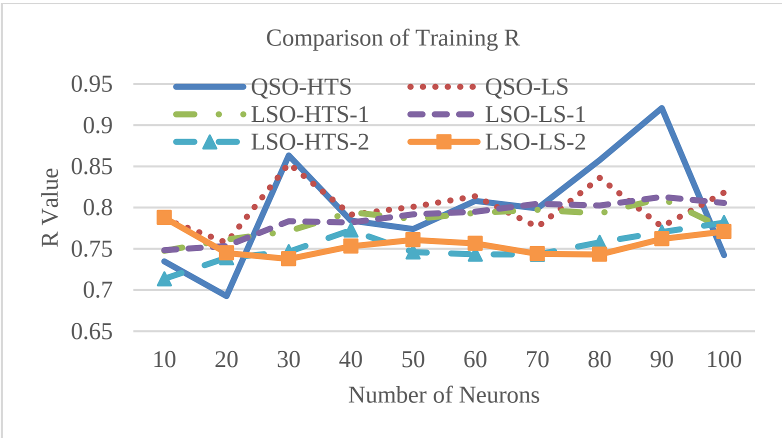


Figure 6.5 Training R Comparison

Figure 6.6 shows the comparison of the test R among six NNs models. It is found that the number of neurons in the hidden layer(s) has a greater influence on the test R with QSO-HTS than others, as the test R of QSO-HTS fluctuates dramatically as the number of neurons varies. It is noted that LSO-HTS-2 with 60 neurons (30 neurons in each hidden layer) has the highest test R (at 0.74659). The details of the test R for each model can be accessed from http://homepage.usask.ca/~yuz703/.

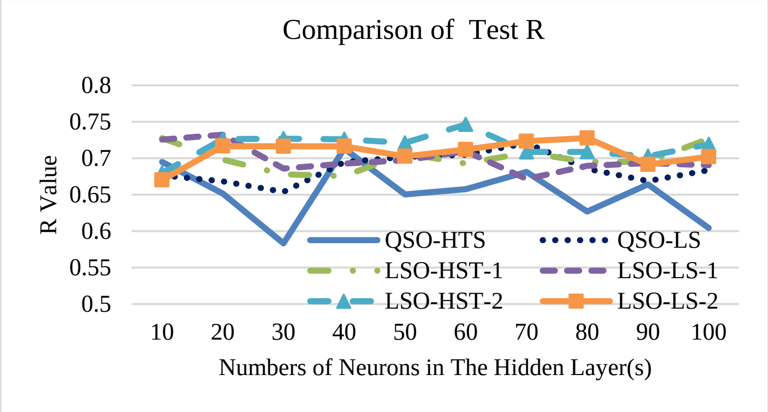


Figure 6.6 Test R Comparison

6.4 Model verification

An experiment was conducted to verify the accuracy of the developed models. Four nurses participated in the experiment. Each of them was asked to fill out a questionnaire. The questionnaire contained 30 affective words with five-level Likert Scale. All affective words were ranked by the nurses in terms of their feelings about nursing scrubs (Figure 6.7 shows the nursing scrubs currently in use in hospitals in Canada). This provided the necessary data to obtain AW. The next step is to use the AW as input to the AW-TO-ADP mapping model to obtain the ADPs. The four nurses evaluated the AW with respect to the ADP, respectively, to give four sets of AWs. Then, the nurse-determined AW was taken as input to the NN model LSO-HST-2 (two hidden layers with 30 neurons in each hidden layer, and HST as the hidden activation function) (the best model for AW-TO-ADP mapping, see Section 6.3), and the NN model produces four sets of output (i.e., four sets of ADPs). The obtained four sets of ADPs were taken as inputs to a simulation software called Marvelous Designer (MD). The four outputs of the MD were the pictures of nursing scrubs. Figure 6.8 was one of the four outputs, and all outputs can be accessed on http://homepage.usask.ca/~yuz703/. Further, the simulated scrubs were shown to the participating nurses (respectively) for their feedback on whether the nursing scrubs with the ADPs meet their affective requirements. The feedback on the scrubs includes the degree of satisfaction regarding color, material, shoulder design, waist design, hem design and overall design of scrubs. It has been found that 100% of the nurses were satisfied with the color of the nursing scrubs, 75% were satisfied with the material, 75% were satisfied with the shoulder design, 75% were satisfied with the waist design, 75% were satisfied with the hem design, and 100% were satisfied with the overall scrubs design; almost all of them believed that the overall scrubs design meets their requirements and expectations. Affective requirements obtained from the participants (nurses) are accessed from http://homepage.usask.ca/~yuz703/.

Figure 6.7 Nursing scrubs currently used in Canada
(http://www.vwmin.org/medical-nursing-scrubs. Retrieved February 20, 2015)

Figure 6.8 One of the simulated nursing scrubs through Marvelous Designer

6.5 Concluding remarks

In this chapter, the development of the AW-TO-ADP mapping model was described. The technique used to develop the model was NNs. Both conventional NNs and Higher-Order NNs models were used. It is interesting to see that the Higher-Order NNs model has not shown superiority to the conventional NNs model. A brief experimental verification of the AW-TO-ADP model was conducted, which shows a great promise of the mapping model as developed.

CHAPTER 7 VALIDATION

The goal of this chapter is to validate the theories developed in the preceding chapters. The theories developed include (1) the systematic design process for apparel products (Chapter 4), (2) a database of affective words in apparel design (Chapter 5), and (3) the mapping from human's affect to apparel design (Chapter 6). The methodology of research was to discuss some real apparel design cases with the available consensuses in the apparel design community as well as the public or society about good or bad effects or influences of the apparel. Then, the theories developed were applied to these cases to predict effects or influences of the apparel. Comparison of the predicted results with the theories and the available consensuses would then provide evidence for the validity of the theories. To this end, Section 7.1 discusses a well-known poor apparel design case, in particular, showing the analysis of potential roots that lead to the poor effect of the apparel product concerned in the case. Section 7.2 discusses the apparel used by health-care personnel, in particular, applying the theory of the affective apparel design to the analysis of the hospital gowns in Canada and China to predict their affective implications, respectively. A conclusion is drawn in Section 7.3.

7.1 Case 1: zoot suit

7.1.1 The zoot suit and consensus

The zoot suit is a men's suit with high-waist; wide-legged, tight-cuffed, pegged trousers; and a long and oversized jacket with giant collars and wide padded shoulders (Figure 7.1(a) and Figure 7.1(b)) (Walker, 1992; Maddan, 2007). The zoot suit first appeared in the 1930s, and it was very popular among African American, Chicano, Filipino American and Italian American men during the 1940s (Walker, 1992; Maddan, 2007). During the 1930s, the economy was in recession, and the atmosphere was one of worry and anxiety.

Figure 7.1 Zoot suit; (a) Layout of Zoot suit (Esquire, 2015) (b) details of Zoot suit (http://www.chictopia.com/photo/show/407926-Inspiration+of+the+day+the+zoot+suit-charcoal-gray-wool-suit. Retrieved June 14, 2015)

During World War II, the zoot suit was condemned by the U.S. government as wasteful (Unger, 2011), and thus it was not seen as respectful or patriotic (Banales, 2015). The zoot suit has been labelled as one of the worst designs (Esquire, 2015). It was abandoned for quite a long time, and recently was revived only recently to depict gangsters at fancy dress parties (Esquire, 2015).

7.1.2 Phenomenon and consensus

Phenomenon 1: the suit design has a high waist (which is up to the upper body) and a long jacket. **Consensus 1:** the suit design wasted materials or used materials in an excessive way. **Consensus 2:** the suit design is comical in appearance, and, in particular, the suit appeared to have overly large clearances for wrapping up the body. The suit was not appropriate for use in the general population but rather should have been limited to use in comedies.

7.1.3 Analysis and discussion

The theoretical development described in the previous chapters will be applied to the current design of the zoot suit to show whether the identified phenomenon and consensuses can be predicted by the theories developed in this thesis.

First, the main requirements, covering the function, ease of wear (ergonomics), and affect (aesthetics), which are together termed as FEA (F: function, E: ergonomics, A: aesthetics), are identified as follows:

FEA-R1 (requirement): maintain warm in the weather temperature range of x to y.
FEA-R2: facilitate the movement of limbs.
FEA-R3: be consistent with the mood of people at that time (1930s).
FEA-R4: economical (especially in the aspect of material usage).

FEA-R1 can be further decomposed into:
FEA-R1.1: use of materials with low thermal conductivity.
FEA-R1.2: coverage of the parts of the body excepting limbs.
FEA-R1.3: coverage of arms.
FEA-R1.4: coverage of legs.

FEA-R2 can be further decomposed into:
FEA-R2.1: movement of arms relative to the upper body.
FEA-R2.2: movement of legs relative to the lower body.

Now, let us pick up the ADPs from the zoot suit design, as follows:
ADP1.1: cashmere which has a low thermal conductivity.
ADP1.2: apparel for the body part except limbs.
ADP1.3: jacket (large and extra-large).
ADP1.4: trousers (large and extra-large).

Figure 7.2 shows the association between the ADP and FEA-R, from which a couple of facts can be identified. First, design is highly coupled and to a particular FEA-R, there is a redundant design. ADP1.3 fulfills FEA-R1.3 in full while fulfills FEA-R1.4 in part. ADP1.4 fulfills FEA-

R1.4 in full while fulfills FEA-R1.3 in part. Therefore, there are redundancies in terms of function on FEA-R1.3 and FEA-R1.4 (i.e., the ADP1.3 and ADP1.4 have a large overlapping area around the interface between the upper body and lower body). According to Design Rule 2 discussed in Section 4.2.5, this is a design error (error 1) that further corresponds to Phenomenon 1 as mentioned before and further, the finding of error 1 is in agreement with Consensus 1. Further, ADP1.3 (ADP1.4) gives inadequate design to achieve FEA-R1.3 (i.e. too much allowance to the body, also accounted for by violating Design Rule 2) (error 2), which is coincident with Consensus 1. Finally, the comical affect or emotion or feeling could be the joint effect from the two design errors (error 1 & error 2, also accounted for by violating Design Rule 1), which is in agreement with Consensus 2.

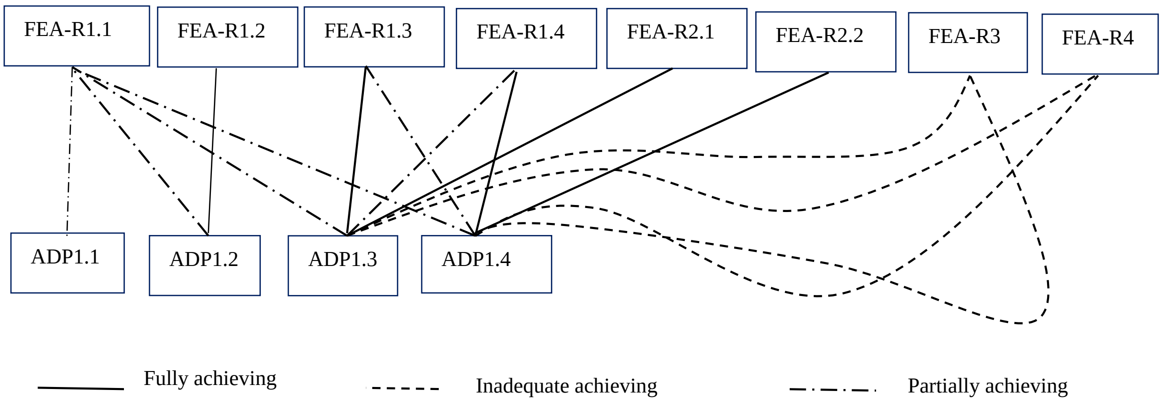


Figure 7.2 The ADP and FEA relationship for the zoot suit design

7.2 Case 2: hospital gown

Cultural difference is an important area to be considered in affective design or design for affect (DFF). For instance, in the Netherlands, the most popular color is blue (owing to a geographical feature of the Netherlands, which is out of the scope of this thesis), while in Spain, light brown color is the most popular color. This section shows that the mapping of ADP-TO-AW could result in the affective words for the hospital gown, which are in agreement with the cultural difference (Chinese and Canadian in particular).

7.2.1 Comparison of the Canadian culture and the Chinese culture in the hospital gown

Several observations of the Canadian hospital culture and the Chinese hospital culture are made as follows:

Observation 1: In Canada, patients and their family members trust doctors and nurses. Patients are looked after by doctors and nurses in hospital. However, in China, patients and family members do not trust doctors and nurses; thus, family members usually stay with patients in hospital and look after them all the time.

Observation 2: In Canada, it is rare that a patient's relatives and friends come to visit a patient in person in hospital; instead, the relatives and friends send flowers with greeting cards to the patient through a delivery system. In China, the relatives and friends often visit patients in person in hospital. Thus, there are many occasions for patients to meet with visitors in hospital.

Observation 3: In Canada, patients are quite independent in that they tend to manage many of their own tasks, such as putting on and taking off their hospital gown. In China, family numbers give help to patients for these kinds of activities in addition to psychological support.

Observation 4: In Canada, patients have to unconditionally follow the instruction from doctors and nurses. Aesthetics of the hospital gown seem to be ignored while the functional and ergonomic aspects of the hospital gown seem to be highly weighted. However, in China, the aesthetic aspect of the hospital gown may be still highly weighted.

7.2.2 Analysis of the Canadian hospital gown and the Chinese hospital gown

The Canadian hospital gown and Chinese hospital gown are different in their designs. The Canadian hospital gown is designed to have a single front piece, sleeves, and two back pieces with two ties to hold them together (Cho, 2006). It is called "one-size-fits-all" design in the work of Black & Torlei (2013). The material is cotton or a cotton- polyester blend, and its color is usually light blue (Figure 7.3(a)).

The Chinese hospital gown is designed with two parts: top and pants. The top has long sleeves, collar, and the opening is in the front. The pants have an elastic waistband. The shape of the Chinese hospital gown is pajama-like (Figure 7.3(b)). The Chinese hospital gown comes in different sizes, including small, medium, large, and extra-large. The Chinese hospital gown is usually made of cotton or a cotton-polyester blend, and it is white with grey vertical stripes.

Figure 7.3 Hospital gown; (a) Canadian hospital gown (http://www.cantexdistribution.com/products/345-patient-gown-vat-dyed/. Retrieved July 8, 2015); (b) Chinese hospital gown (http://www.shrunfei.com/product/nannvshibingyuanfu.htm. Retrieved July 8, 2015)

In the following, analysis is given to generate the affective words for the two gowns to see whether they are in agreement with the observations as mentioned before.

Apparel design parameters (ADPs) of the hospital gown include: hue, saturation, value, stretch, bending, buckling, damping, density, shoulder, waist, and hem (RE: Chapter 6). The settings of the ADPs for the Canadian hospital gown and Chinese hospital gown are summarized as follows based on the existing hospital gowns (Table 7.1).

In Chapter 6, the mapping of AW-TO-ADP was developed. In order to perform an analysis of an existing apparel product, there is a need to have the mapping of ADP-TO-AW. This mapping was built in the same way as the mapping of AW-TO-ADP (RE: Chapter 6), in particular, by employing the linear synaptic operation (LSO) (Chakra, 2013). Note that all the training data were taken from the same data for developing the mapping of AW-TO-ADP. The structure of LSO was seen in Table 7.2.

Table 7.1 ADPs of the hospital gown

ADP	Canadian hospital gown	Chinese hospital gown
Hue	196	0
Saturation	63	0
Value	97	70
Stretch	140	140
Bending	76	76
Buckling	80	80
Damping	1	1
Density	27	27
Shoulder	44	38
Waist	77	69
Hem	110	90

Table 7.2 Structure of LSO

Parameters	LSO
Numbers of layers	3
Numbers of hidden layer(s)	1
Training algorithm	Levenber-Marquardt BP
Data normalization	[0, 1]
Active function (output layer)	LS
Active function (hidden layer)	HTS
Number of hidden neurons	40
Data division	60% for training, 10% for validation and 30% for test

Table 7.3 shows the result, in which the affective words with the corresponding five-level Likert scales are given.

Table 7.3 Score of affective words obtained from mapping model

Affective Word	Canada	China	Affective Word	Canada	China
classic	4.381	4.482	dramatic	2.842	2.700
stylish	4.067	3.791	romantic	2.766	2.151
soft	3.830	4.223	boyish	1.178	1.452
casual	3.410	4.332	sporty	1.514	2.099
feminine	4.476	4.549	conservative	3.836	4.137
sexy	3.975	3.886	exclusive	1.840	1.351
cute	3.159	3.122	practical	3.261	3.824
unique	2.684	2.335	slouchy	1.304	1.717
edgy	3.357	3.427	youthful	3.120	3.358
sophisticated	3.278	2.444	glamorous	3.068	2.703
comfortable	3.355	3.860	understated	2.270	2.658
playful	2.111	2.195	androgynous	1.783	2.266
trendy	3.812	4.016	bohemian	1.730	1.402
vibrant	2.810	2.744	professional	4.307	4.099
delicate	3.741	3.743	unconventional	2.127	2.444

Table 7.3 shows that the Canadian hospital gown is viewed as more professional than the Chinese hospital gown. The higher rating of "professional" suggests that the Canadian patient is more engaged with doctors and nurses. The underlying cause of this is the trust between the doctor/nurse and patient, which is in agreement with Observation 1.

Table 7.3 also shows that the Canadian hospital gown is less casual, understated, and slouchy but more sophisticated than the Chinese one. The lower scores on "casual" and "slouchy" and the high score on "sophisticated" of the Canadian hospital gown suggest that the Canadian hospital gown is specially tailored to the context that patients are largely with doctors and nurses. In contrast, the Chinese hospital gown is very similar to the apparel in a conventional situation as pajamas (as mentioned before), which is tailored to the context that patients are engaged with members at home and office. The result of this analysis is therefore in agreement with Observation 2.

Table 7.3 shows that the Canadian hospital gown is more exclusive than the Chinese one. The higher score of "exclusive" suggests that the Canadian patients deal with many issues themselves unlike the Chinese patients who get assistance from their family members. The result of this analysis is therefore in agreement with Observation 3.

Table 7.3 shows that the Canadian hospital gown is less trendy and delicate than the Chinese one. Less “trendy” and “delicate” suggests that the Canadian hospital gown has less sense of aesthetics. The result of this analysis is thus in agreement with Observation 4.

It may be clear that the mapping of ADP-TO-AW is effective for the analysis of apparel products. Since the mapping of ADP-TO-AW is a reverse mapping of AW-TO-ADP, it is reasonable to infer that the mapping of AW-TO-ADP is also effective.

7.3 Concluding remarks

The two examples of apparel design were discussed in this chapter. Both were about the analysis of the existing known apparel by using the theories and methodologies developed in this thesis. The first theory is the rational and systematic design process for apparel, and the second theory is the affective design methodology. In both cases, the results of the analysis were in strong agreement with the known facts or phenomena, observations, and consensus. This then has given evidence that the theory and methodology developed in this thesis will be useful in apparel design practice.

CHAPTER 8 CONCLUSIONS AND FUTURE WORK

8.1 Overview and conclusions

This thesis presents work for achieving effective computer-aided design of apparel products. The study was motivated by three observations. The first of these is that because Computer-aided Design of Apparel (CADOA) is still in its infancy, it currently is at most a tool for facilitating drawing and animation. Its programs are not well integrated, so the intelligence level as well as effectiveness of CADOA is restricted. A bottle-neck problem inherent in this situation is that the current CADOA system lacks an ontology model for the apparel product. The second motivating observation is that there is difficulty in constructing a better design and manufacturing process such that the design of apparel products could be more rational and systematic. The third observation is that there is difficulty in capturing a customer's affective response, response that is necessary for the designing of apparel that will meet the customer's affective need.

Three objectives were proposed to address the problems articulated in the three observations, and those objectives are revisited below.

Objective 1: To develop a conceptual model (or domain model or ontology model) for apparel products such that the basic notions behind the domain of apparel are captured and defined to facilitate the integration of various design "experts," including computer-based expert systems or agents. The conceptual model as developed should demonstrate its promise in the integration of various CAODA systems as well as in the interface with customers.

Objective 2: To develop a systematic and rational design process for apparel products. "Systematic" indicates development by a step-by-step procedure, while "rational" means that objectivity in decision-making is preserved (Pahl et al., 2007).

Objective 3: To develop a database of vocabularies in the context of apparel and apparel design that enables a customer's affective responses to be expressed and to develop their relationship with the apparel design parameters that enables to determine suitable design parameters of an apparel product which may exhibit the customer's affective responses.

These objectives have been achieved, and the detailed description of the work related to these objectives has been presented in the preceding chapters. The comprehensive literature review presented in Chapter 2 provides justification and confirmation of the need to conduct this study. Chapter 3 presents the building of the conceptual model for apparel products, along with validation of the model by examples. Chapter 4 offers the development of a systematic and rational apparel design process, as well as the validation of the process. Chapter 5 shows the development of a unique methodology by which to compile vocabularies for representing a human's affect or emotion in the domain of apparel, along with the database for those vocabularies. Chapter 6 exhibits the development of the mapping from the affective vocabularies or words compiled in Chapter 5 to the apparel design parameters. Chapter 7 presents two case studies to demonstrate the usefulness of the theories and methodologies presented in Chapters 4, 5, and 6, respectively. The work leads to the following conclusions:

First, development of a highly integrated CADOA is now possible with the ontology model of the apparel structure and the design process model for apparel, as developed in this thesis. The customized model for the apparel structure with individual CADOA systems is only an external view of the ontology model, and the customized model for apparel design with individual CADOA systems is only a specific process of the more general apparel design process model. Therefore, the two models (apparel structure and apparel design) can be shared by all CADOA systems, and thus they can be utilized by apparel designers in an integrated manner, increasing the degree of intelligence of CADOA systems.

Second, a systematic and rational apparel design process, as developed in this thesis, shows strong positive potential to improve the apparel design practice in terms of improving design creativity and design efficiency. It is noted that the design process model does not exclude the designer's and/or customer's participation in design, i.e., the apparel design process can never be automated due to the significant portion of design decisions being on the affect which is inherently subjective. In fact, the systematic and rational process is only meant to the portion of design that is objective, which is nevertheless supportive to the subjective portion of design. The fact that the proposed design process possesses the open-endedness and iteration means to increase the human participation at large, but human participation is structuralized and well organized (owing to the presence of the model).

Third, it is feasible to conduct apparel design that takes into account of the wearer's affects in a way that has a trade-off between the objectivity and subjectivity in design. The objectivity part of design is fulfilled by the AW-TO-ADP mapping. However, this mapping does not cover all the design process for apparel. Acquisition of AWs still needs to have inputs from the customer and his or her discussion with the designer. After the ADP is generated by the AW-TO-ADP mapping model, the ADP is merely taken to the designer as a reference (i.e., the future CADOA system will have an interface to the designer), and the designer can make change on the generated ADP. This enabler is thanks to the ontology model and the design process model, as they offer a management role for all the changes made by the designer. Further, after the designer makes a final decision on the ADP, the 3D apparel which resembles the real apparel, will be displayed to the customer (i.e., the future CADOA system will have an interface to the customer) for his or her feedback.

8.2 Contributions

Several contributions are made with this thesis. First is the provision of a comprehensive ontology model for apparel and apparel design, which gives a basis for future further development in computer-aided design and manufacturing of apparel. Second is the provision of a general apparel design process model that provides a reference model for any specific apparel design process. Third is the provision of a new data-mining approach that acquires human language for expression of affects, along with a database of that language. It should be noted that this approach is very general in the sense that it is domain-independent. The final contribution is the provision of an algorithm to search apparel design parameters given by apparel feeling words. The database of affective words or vocabularies and the algorithm can be readily incorporated in the existing CADOA commercial software systems, thus enabling not only functional and ergonomics design but also affective design.

8.3 Future work

Along with the work presented in this thesis, several initiatives have emerged for future consideration, as discussed below.

First, there is a need to develop a database of affective design cases that will more efficiently support consideration of affects in apparel design. Each case should include the following architecture: (1) functional, ergonomic, and affective requirements, (2) design parameters for the functional and ergonomic features, and (3) design parameters for the affective features. Further, the information from (1) and (2) will serve as a context for the information arising from (3). It should be noted that the mapping from affective words to design parameters, as developed in this thesis lacks specific contexts, which may create conflicts in design between the affect and function or comfort. By introducing the notion of the context into the cases, the affective design is expected then to be conducted in a way that the affect can be compatible and/or consistent and/or congruent with both function and comfort.

Second, the question arises: What is the relationship shared by the runway model, the fashion she/he is exhibiting and the audience? Failure in understanding or answering this question can cause problems involving effective selection of suitable runway models for displaying particular articles of fashion in the context of specific fashion shows. Therefore, future research is needed to study this question and address the corresponding issue. Experiments need to be designed that will answer that relationship question.

Finally, it would be interesting to study the feasibility of a future apparel industry following the paradigm called "mass personalization in apparel." An apparel industry that comprised the philosophy of mass personalization in apparel would be evidenced by the following scenario: (1) A person desires a particular apparel product; (2) Via the Internet, she/he visits an apparel e-factory to briefly dialogue with a relational agent; (3) Several hours later, the apparel, which is customized to the customer's need and desire, will be mailed to that person. Further, if a particular e-factory is unable to meet the manufacturing needs for the required apparel, it may outsource the work to another factory capable of rapidly producing the apparel product using technology such as 3D printing.

REFERENCES

1. Alavala, C. R. (2008). Fuzzy Logic and Neural Networks: New Age International.
2. Anitawati, M., Laila, N., & Nagamachi, M. (2007). Kansei engineering: a study on perception of online clothing websites. Paper presented at the The 10th International Conference on Quality Management and Operation Development. Linköping University Electronic Press, Sweden.
3. Anitawati, M., Laila, N., & Nagamachi, M. (2008). Kansei structure and visualization of clothing websites cluster. Paper presented at the Information Technology, 2008. ITSim 2008. International Symposium on.
4. Antonie, M. L., Zaiane, O. R., & Coman, A. (2001). Application of data mining techniques for medical image classification. Paper presented at the Proceedings of the Second International Workshop on Multimedia Data Mining, MDM/KDD'2001, San Francisco, CA, USA.
5. Ayada, M., Miki, M., & Niwa, M. (1991). Discriminating the silhouette of ladies'garments based on fabric mechanical properties. International Journal of Clothing Science and Technology, 3(3), 18-27.
6. Banales, K. C. (2015). The zoot suits, 1940s, Retrieved June 14, 2015, from https://www.mtholyoke.edu/~campo22k/classweb/Zoot%20Suits/.
7. Bi, Z. M., Lin, Y., & Zhang, W. J. (2010). The general architecture of adaptive robotic systems for manufacturing applications. Robotics and Computer-Integrated Manufacturing, 26(5), 461-470.
8. Borges, J., & Levene, M. (2000). Data mining of user navigation patterns web usage analysis and user profiling, Springer, 92-112.
9. Borrett, J. (2008). The turning of the tides: the history of Neanderthal research. Retrieved July 18, 2015, from http://www.theposthole.org/sites/theposthole.org/files/downloads/posthole_27_194.pdf.
10. Black, S. and Torlei, K. (2013). Designing a new type of hospital gown: a user-centered design approach case study. Fashion Practice, vol. 5, pp. 153-160.
11. Burns, L. D. & Bryant, N. O. (2002). The business of fashion: designing, manufacturing, and marketing: Fairchild.
12. Bye, E., & Hakala, L. (2005). Sailing apparel for women: a design development case study. Clothing and Textiles Research Journal, 23(1), 45-55.
13. Carr, H., & Pomeroy, J. (1992). Fashion design and product development: Blackwell.

14. Chakra, N. C., Song, K. Y., Gupta, M. M., & Saraf, D. N. (2013). An innovative neural forecast of cumulative oil production from a petroleum reservoir employing Higher-order Neural Networks (HONNs). Journal of Petroleum Science and Engineering, 106, 18-33.
15. Chakrabarti, S., Ester, M., Fayyad, U., Gehrke, J., Han, J., Morishita, S., Wang, W. (2006). Data mining curriculum: a proposal (Version 1.0). Intensive Working Group of ACM SIGKDD Curriculum Committee.
16. Charfi, H., Gagalowicz, A., & Brun, R. (2006). Measurement of viscosity damping parameters of fabric related to a non-linear textile model. Textile research journal, 76(10), 787-798.
17. Chen, Y., Zeng, X., Happiette, M., Bruniaux, P., Ng, R., & Yu, W. (2009). Optimisation of garment design using Fuzzy Logic and sensory evaluation techniques. Engineering Applications of Artificial Intelligence, 22(2), 272-282.
18. Cho, H. S., & Lee, J. (2005). Development of a macroscopic model on recent fashion trends on the basis of consumer emotion. International Journal of Consumer Studies, 29(1), 17-33.
19. Cho, K. (2006). Redesigning hospital gowns to enhance end users' satisfaction. Family and Consumer Sciences Research Journal, vol. 34, pp. 332-349.
20. Costa, P., & McCrae, R. Professional manual: revised neo personality inventory (NEO-PI-R) and NEO five-factor-inventory (NEO-FFI). (1992). Odessa, FL: Psychological Assesment Resources.
21. Costa, P., & McCrae, R. (2000). Professional manual: revised neo personality inventory (NEO-PI-R) and NEO five-factor inventory (FFI) professional manual: Lutz (FL): Psychological Assessment Resources.
22. Daanen, H., & Hong, S. A. (2008). Made-to-measure pattern development based on 3D whole body scans. International Journal of Clothing Science and Technology, 20(1), 15-25.
23. Date, C. J. (1986). An introduction to database systems (Vol. 7). Reading, Mass.: Addison Wesley.
24. Dictionary.com, Costume. (2015c). Retrieved March 8, 2015, from http://dictionary.reference.com/browse/costume.
25. Dictionary.com, Dart. (2013b). Retrieved November 11, 2013, from http://dictionary.reference.com/browse/dart.
26. Dictionary.com, Emotion. (2015a). Retrieved June 1, 2015, from http://dictionary.reference.com/browse/emotion?s=t.

27. Dictionary.com, Silhouette. (2013a). Retrieved December 12, 2013, from http://dictionary.reference.com/browse/silhouette.
28. Dictionary.com, Sustainability. (2015b). Retrieved February 1, 2015, from http://dictionary.reference.com/browse/sustainability.
29. Dunne, L. E. (2004). The design of wearable technology: addressing the human-device interface through functional apparel design. Cornell University.
30. Esquire (2015). The top 10 worst fashion trends in history, Retrieved June 10, 2015, from http://www.esquire.co.uk/style/article/6087/worst-mens-fashion-trends-in-history/.
31. Etzioni, O. (1996). The world-wide Web: quagmire or gold mine? Communications of the ACM, 39(11), 65-68.
32. Gam, H. J., Cao, H., Farr, C., & Heine, L. (2009). C2CAD: a sustainable apparel design and production model. International Journal of Clothing Science and Technology, 21(4), 166-179.
33. Gaskill, L. R. (1992). Toward a model of retail product development: a case study analysis. Clothing and Textiles Research Journal, 10(4), 17-24.
34. Gupta, D. (2011). Design and engineering of functional clothing. Indian Journal of Fibre and Textile Research, 36(4), 327.
35. Gupta, M. M. (2008). Correlative type higher-order neural units with applications. In: Proceedings of the IEEE International Conference on Automation and Logistics, ICAL, pp. 715–718.
36. Gupta, M. M., Homma, N., Hou, Z.-G., Solo, A. M. G., Bukovsky, I., (2010). Higher-order Neural Networks: fundamentals theory and applications. In: Zhang, M. (Ed.), Artificial Higher-Order Neural Networks for Computer Science and Engineering: Trends for Emerging Applications. Information Science Reference, Hoboken, New Jersey, pp. 397–422.
37. Gupta, M. M., Jin, L., Homma, N. (2003). Static and dynamic Neural Networks: from fundamentals to advanced theory, 1st ed. Wiley IEEE Press, Hoboken, New Jersey.
38. Gupta, M. M. & Rao, D.H. (1993). Neuro control systems-theory and applications: IEEE Neural Networks Council.
39. Heaton, J. (2008). Introduction to Neural Networks for C#: Heaton Research, Inc.
40. IBM SPSS. (2015). IBM SPSS conjoint 22. Retrieved July 27, 2015, from http://library.uvm.edu/services/statistics/SPSS22Manuals/IBM%20SPSS%20Conjoint.pdf.

41. Ingham, R., & Covey, L. (1992). The costume technician's handbook: a complete guide for amateur and professional costume technicians. Heinemann Educational Publishers.
42. Ishihara, S., Ishihara, K., Nagamachi, M., & Matsubara, Y. (1997). An analysis of Kansei structure on shoes using self-organizing Neural Networks. International Journal of Industrial Ergonomics, 19(2), 93-104.
43. Ishihara, S., Nagamachi, M., & Ishihara, K. (2008). Analyzing Kansei and design elements relations with PLS. In The 10th International Conference on Quality Management and Operation Development.
44. Jackson, T., & Shaw, D. (2006). The fashion handbook: Routledge New York.
45. Jindo, T., & Hirasago, K. (1997). Application studies to car interior of Kansei engineering. International journal of industrial ergonomics, 19(2), 105-114.
46. Khalid, H. M., & Helander, M. G. (2006). Customer emotional needs in product design. Concurrent Engineering, 14(3), 197-206.
47. LaBat, K. L., & Sokolowski, S. L. (1999). A three-stage design process applied to an industry-university textile product design project. Clothing and Textiles Research Journal, 17(1), 11-20.
48. Lamb, J. M., & Kallal, M. J. (1992). A conceptual framework for apparel design. Clothing and Textiles Research Journal, 10(2), 42-47.
49. Lapedes, A., & Farber, R. (1987). Nonlinear signal processing using Neural Networks: Prediction and system modelling.
50. Li, J., & Li, Y. (2012). Cognitive model based fashion style decision making. Expert Systems with Applications, 39(5), 4972-4977.
51. Lim, H., & Istook, C. L. (2011). Drape simulation of three-dimensional virtual garment enabling fabric properties. Fibers and Polymers, 12(8), 1077-1082.
52. Lin, Y., & Zhang, W. (2006). Integrated design of function, usability, and aesthetics for automobile interiors: state of the art, challenges, and solutions. Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering, 220(8), 697-708.
53. Liu, X., Ghorpade, A., Tu, Y. L., & Zhang, W. J. (2012). A novel approach to probability distribution aggregation. Information Sciences, 188, 269-275.
54. Lokman, A. M., & Aziz, A. A. (2010). A Kansei system to support children's clothing design in Malaysia. Paper presented at the Systems Man and Cybernetics (SMC), 2010 IEEE International Conference on.

55. Lokman, A. M., Noor, N., & Nagamachi, M. (2008). Kansei database system for emotional interface design of e-commerce website. Paper presented at the 4th International Cyberspace Conference on Ergonomics.
56. Lokman, A. M., Noor, N. L. M., & Nagamachi, M. (2009). Expert Kansei Web: a tool to design Kansei website. In Enterprise Information Systems, Springer Berlin Heidelberg, pp. 894-905.
57. Madria, S. K., Bhowmick, S. S., Ng, W. K., & Lim, E. P. (1999). Research issues in web data mining data warehousing and knowledge discovery. Springer, pp. 303-312.
58. Mahar, T., Ajiki, I., Dhingra, R., & Postle, R. (1989). Fabric mechanical and physical properties relevant to clothing manufacture: part 3: shape formation in tailoring. International Journal of Clothing Science and Technology, 1(3), 6-13.
59. May-Plumlee, T., & Little, T. J. (1998). No-interval coherently phased product development model for apparel. International Journal of Clothing Science and Technology, 10(5), 342-364.
60. Maddan, H., (2007). Zooting up/brighten prom night with flash, dash and panache, The San Francisco Chronicle. Retrieved March 8, 2015, from http://www.sfgate.com/living/article/Zooting-up-Brighten-prom-night-with-flash-dash-2598703.php.
61. McCann, J., Hurford, R., & Martin, A. (2005). A design process for the development of innovative smart clothing that addresses end-user needs from technical, functional, aesthetic and cultural view points. Paper presented at the Wearable Computers. Proceedings. Ninth IEEE International Symposium on.
62. Mitsui, H., & Christie, R. D. (1997). Visualizing voltage profiles for large scale power systems. Computer Applications in Power, IEEE, 10(3), 32-37.
63. Moody, W., Kinderman, P., & Sinha, P. (2010). An exploratory study: relationships between trying on clothing, mood, emotion, personality and clothing preference. Journal of Fashion Marketing and Management, 14(1), 161-179.
64. Na, Y. (2009). Fashion design styles recommended by consumers' sensibility and emotion. Human Factors and Ergonomics in Manufacturing & Service Industries, 19(2), 158-167.
65. Nagamachi, M. (1995). Kansei engineering: a new ergonomic consumer-oriented technology for product development. International Journal of industrial ergonomics, 15(1), 3-11.
66. Nagamachi, M. (2002). Kansei engineering as a powerful consumer-oriented technology for product development. Applied ergonomics, 33(3), 289-294.

67. Nagamachi, M., Okazaki, Y., & Ishikawa, M. (2006). Kansei engineering and application of the rough sets model. Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering, 220(8), 763-768.
68. Nakada, K. (1997). Kansei engineering research on the design of construction machinery. International Journal of Industrial Ergonomics, 19(2), 129-146.
69. Nance, D. R. (2009). An analysis of fashion and costume design processes. Master dissertation, NC State University.
70. Ngai, E. W., Xiu, L., & Chau, D. C. (2009). Application of data mining techniques in customer relationship management: a literature review and classification. Expert systems with applications, 36(2), 2592-2602.
71. Niwa, M., Nakanishi, M., Ayada, M., & Kawabata, S. (1998). Optimum silhouette design for ladies' garments based on the mechanical properties of a fabric. Textile research journal, 68(8), 578-588.
72. Pahl, G., Wallace, K., and Blessing, L. (2007). Engineering design: a systematic approach, Springer Science & Business Media.
73. Rajaraman, A., & Ullman, J. D. (2011). Mining of massive datasets: Cambridge University Press.
74. Ramos, J. (2003). Using TF-IDF to determine word relevance in document queries. Paper presented at the Proceedings of the First Instructional Conference on Machine Learning.
75. Raunio, A.M. (1982). Favorite clothes–a look at individuals' experience of clothing. Clothing and its Social, Psychological, Cultural and Environmental Aspects. Research Report No. 161, 179-194.
76. Sarcar, M., Rao, K. M., & Narayan, K. L. (2008). Computer-aided design and manufacturing: PHI Learning Pvt. Ltd.
77. Schütte, S. T., Eklund, J., Axelsson, J. R., & Nagamachi, M. (2004). Concepts, methods and tools in Kansei Engineering. Theoretical Issues in Ergonomics Science, 5(3), 214-231.
78. Schwarz, M. W., Cowan, W. B., & Beatty, J. C. (1987). An experimental comparison of RGB, YIQ, LAB, HSV, and opponent color models. ACM Transactions on Graphics (TOG), 6(2), 123-158.
79. Sedgwick, J., Henson, B., & Barnes, C. (2003). Sensual surfaces: engaging consumers through surface textures. Paper presented at the Proceedings of the 2003 International Conference on Designing pleasurable products and interfaces.

80. Shieh, M. D., & Cheng, C. C. (2003). Development of an intelligent fabric retrieval System using Computer-Based Kansei Algorithm.

81. Shimizu, Y., Sadoyama, T., Kamijo, M., Hosoya, S., Hashimoto, M., Otani, T., Honywood, M. (2004). On demand production system of apparel on the basis of Kansei engineering. International journal of clothing science and technology, 16(1/2), 32-42.

82. Sola, J., & Sevilla, J. (1997). Importance of input data normalization for the application of Neural Networks to complex industrial problems. Nuclear Science, IEEE Transactions on, 44(3), 1464-1468.

83. Suh, N. P. (2001). Axiomatic design: advances and applications. The Oxford Series on Advanced Manufacturing.

84. Tanoue, C., Ishizaka, K., & Nagamachi, M. (1997). Kansei Engineering: a study on perception of vehicle interior image. International Journal of Industrial Ergonomics, 19(2), 115-128.

85. Unger, M. (2011). The zoot suit: an all-American fashion that changed history. Penn Current. Retrieved June 7, 2015, from http://www.upenn.edu/pennnews/current/2011-04-07/research/zoot-suit-all-american-fashion-changed-history.

86. Walker, J. A., (1992). Glossary of art. Architecture & Design since 1945. GK Hall.

87. Wang, C. (2008). Understanding and modeling of aesthetic response to shape and color in car body design. University of Saskatchewan.

88. Wang, J. W., Wang, H. F., Ding, J. L., Furuta, K., Kanno, T., Ip, W. H., & Zhang, W. J. (2013). On domain modelling of the service system with its application to enterprise information systems. Enterprise Information Systems, (ahead-of-print), 1-16.

89. Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. Journal of personality and social psychology, 54(6), 1063.

90. Wong, A., Li, Y., Yeung, P., & Lee, P. (2003). Neural Network predictions of human psychological perceptions of clothing sensory comfort. Textile research journal, 73(1), 31-37.

91. Zhang, W. J. (1994). An integrated environment for CAD/CAM of mechanical systems. Doctoral dissertation, University of Delft.

92. Zhang W. J. & Werff K. van der, (1994). A critique of conceptual data modeling notions relative to the machine design domain. Proc. of 1994 ASME Engineering Database Symposium'94, Sept. 11-14, Minneapolis, USA, 59-66.

93. Zhang, W. J., Lin, Y., & Sinha, N. (2011). On the function-behavior-structure model for design. Proceedings of the Canadian Engineering Education Association.

94. Zhao, Y., Montazeri, A., Wang, C., & Zhang, W. J. (2015). On development of methods for expressing customer affective response for apparel products, Proc. CAD'15, London, UK, 315-320. http://dx.doi.org/10.14733/cadconfP.2015.315-320.

APPENDIX A DEFINITION OF A PARTIAL LIST OF APPAREL DESIGN PARAMETERS

Definition A.1. Waist: The circumference of the thinnest area between a person's rib cage and hip. Apparel's size in the waist area is designed in terms of the waist.

Definition A.2. Length: The measurement from the top of apparel to the bottom of apparel.

Definition A.3. Tensile strength: The maximum amount of force that can be applied to a material before breaking the material.

Definition A.4. Shear strength: The maximum amount of force that can be applied to a material before producing a sliding failure on the material.

Definition A.5. Warp extensibility: The extent to which a material can be stretched in the warp direction without causing it to be broken.

Definition A.6. Weft extensibility: The extent to which a material can be stretched in the weft direction without causing it to be broken.

Definition A.7. Bending stiffness: The resistance of a material against the bending deformation.

Definition A.8. Thickness: The distance between two opposite sides of a material.

APPENDIX B ALGORITHM Ⅱ

Table B.1 Algorithm (1): from block to pattern

INPUT: Block (RT_x, wh, HR_x), length, ease_w, ease_hip, dart_width, depth

OUTPUT: Waist, Hip, Hem, $Dart^{left}$, $Dart^{right}$, Depth, O, r_w, r_h.

INITIALIZE coordinates of Waist (W_x, W_y), Hip (H_x, H_y), Hem (Hem_x, Hem_y), $Dart^{left}$ (D_x^l, D_y^l), $Dart^{right}$ (D_x^r, D_y^r), Depth (De_x, De_y,), O (O_x, O_y).

INITIALIZE r_w, r_h, temp.

Step 1:Waist (W_x, W_y) ⇐ (RT_x + ease_w /2, length);

Hip (H_x, H_y) ⇐ (HR_x + ease_hip /2, length-wh);

Step 2:SOLVE $(0 - H_y)(W_x - H_x) = (Hem_x - H_x)(W_y - H_y)$ to get Hem_x % line function

Hem (Hem_x, Hem_y) ⇐ $((\frac{-Hy\,(Wx - Hx)}{Wy - Hy}) + H_x, 0)$;

Step 3:SOLVE $(O_y - H_y)(W_x - H_x) = (0 - H_x)(W_y - H_y)$ to get O_y

O (O_x, O_y) ⇐ $(0, (\frac{-Hx\,(Wy - Hy)}{Wx - Hx}) + H_y)$;

Step 4:$r_h \Leftarrow \sqrt{Hem_x^2 + O_y^2}$;

$r_w \Leftarrow \sqrt{W_x^2 + (O_y - length)^2}$;

Step 5: temp ⇐ $W_x/2$;

D_x^l⇐ temp - dart_width/2;

D_x^r⇐ temp + dart_width/2;

Depth (De_x, De_y,) ⇐ (temp, W_y - depth);

Step 6: SOLVE $(D_x^l - O_x)^2 + (D_y^l - O_y)^2 = r_w^2$ to get D_y^l

SOLVE $(D_x^r - O_x)^2 + (D_y^r - O_y)^2 = r_w^2$ to get D_y^r

Stop

Table B.2 Algorithm (2): 2D pattern composing

INPUT: $Block_f$ (RT_x, wh, HR_x), length, $ease\_w_f$, $ease\_hip_f$, $dart\_width_f$, $depth_f$,

$Block_b$ (RT_x, wh, HR_x), $ease\_w_b$, $ease\_hip_b$, $dart\_width_b$, $depth_b$.

OUTPUT: Plot of Front 2D Pattern, Plot of Back 2D Pattern.

Step 1:CALL Block to Pattern

($Waist_f$, Hip_f, Hem_f, $Dartleft_f$, $Dartright_f$, $Depth_f$, O^f, r_w^f, r_h^f) $\Leftarrow$ Block to Pattern

($Block_f$, length, $ease\_w_f$, $ease\_hip_f$, $dart\_width_f$, $depth_f$);

($Waist_b$, Hip_b, Hem_b, $Dartleft_b$, $Dartright_b$, $Depth_b$, O^b, r_w^b, r_h^b) $\Leftarrow$ Block to Pattern

($Block_b$, $ease\_w_b$, $ease\_hip_b$, $dart\_width_b$, $depth_b$);

Step 2:CALCULATE symmetric vertices of $Waist_f$, Hip_f, Hem_f, $Dartleft_f$, $Dartright_f$, $Depth_f$

$Waist_b$, Hip_b, Hem_b, $Dartleft_b$, $Dartright_b$, $Depth_b$ with respect to the y-axis

DENOTE the symmetric vertices as $Waist_f^s$, Hip_f^s, Hem_f^s, $Dartleft_f^s$, $Dartright_f^s$, $Depth_f^s$,

$Waist_b^s$, Hip_b^s, Hem_b^s, $Dartleft_b^s$, $Dartright_b^s$, $Depth_b^s$.

Step 3:DISPLAY on Figure: Front 2D Pattern

Arc on Circle (O^f, r_w^f) between $Waist_f$ and $Waist_f^s$;

Arc on Circle (O^f, r_h^f) between Hem_f and Hem_f^s;

Line between $Waist_f$ and Hem_f;

Line between $Dartleft_f$ and $Depth_f$;

Line between $Dartright_f$ and $Depth_f$;

Step 4:DISPLAY on Figure: Back 2D Pattern

Arc on Circle (O^b, r_w^b) between $Waist_b$ and $Waist_b^s$;

Arc on Circle (O^b, r_h^b) between Hem_b and Hem_b^s;

Line between $Waist_b$ and Hem_b;

Line between $Dartleft_b$ and $Depth_b$;

Line between $Dartright_b$ and $Depth_b$;

Stop

Table B.3 Algorithm (3): 3D skirt assembling from 2D pattern

INPUT: $Waist_f$, Hip_f, Hem_f, $Dartleft_f$, $Dartright_f$, $Depth_f$ $Waist_b$, Hip_b, Hem_b, $Dartleft_b$, $Dartright_b$, $Depth_b$;

$Waist_f^s$, Hip_f^s, Hem_f^s, $Dartleft_f^s$, $Dartright_f^s$, $Depth_f^s$, $Waist_b^s$, Hip_b^s, Hem_b^s, $Dartleft_b^s$, $Dartright_b^s$, $Depth_b^s$;

Plot of Front 2D Pattern; Plot of Back 2D Pattern.

OUTPUT: Plot of 3D Pattern.

Step 1:INITIALIZE Cartesian coordinate system for a three-dimensional space R^3

Step 2:CREATE a vertex Waist in R^3 to represent $Waist_f$ and $Waist_b$;

CREATE a vertex Waist' in R^3 to represent $Waist_f^s$ and $Waist_b^s$;

CREATE a vertex Hem in R^3 to represent Hem_f and Hem_b;

CREATE a vertex Hem' in R^3 to represent Hem_f^s and Hem_b^s;

CREATE a vertex $Dart_f$ in R^3 to represent $Dartleft_f$ and $Dartright_f$;

CREATE a vertex $Dart_f$' in R^3 to represent $Dartleft_f^s$ and $Dartright_f^s$;

CREATE a vertex $Dart_b$ in R^3 to represent $Dartleft_b$ and $Dartright_b$;

CREATE a vertex $Dart_b$' in R^3 to represent $Dartleft_b^s$ and $Dartright_b^s$;

Step 3: DISPLAY 3D Pattern using Waist, Waist', Hem, Hem', $Dart_f$, $Dart_f$', $Dart_b$, $Dart_b$', $Depth_f$, $Depth_f^s$, , $Depth_b$, $Depth_b^s$, Front 2D Pattern, andBack 2D Pattern

STOP

APPENDIX C CLIPBOARD SNIFFER

Clipboard Sniffer is a program made in-house for automatically collecting the texts in an article. When articles (or webpages) are copied from websites, they are often accompanied by some useless information on the webpages, such as pictures and advertisements. The Clipboard Sniffer program not only eliminates this useless information, but also makes the font uniform. The program also stores the “clean” text in a plain document. The interface and manipulation of Clipboard Sniffer is as follows:

Choose the file pathway for saving the text of an article. Copy the article’s name into the File Name field, and copy the whole article from beginning to the end to the File field. Press Save Anyway. The text of the article will be saved.

Figure C.1 Interface of clipboard sniffer

APPENDIX D ADJECTIVE EXTRACTOR

Adjective Extractor is a program made in-house for automatically scanning and extracting adjectives from the text of an article stored in the plain text format made by Clipboard Sniffer (appendix C). The tool is built up with reference to WardNet of All English Adjectives to help identify adjectives from texts. The interface and manipulation of Adjective Extractor is as follows:

Open the folder which contains the text of an article in Corpus Folder. Press Extract. Adjectives will be displayed in the field to the left of the Save As button. Press Save As to save the adjectives; then, press Quit to end the program.

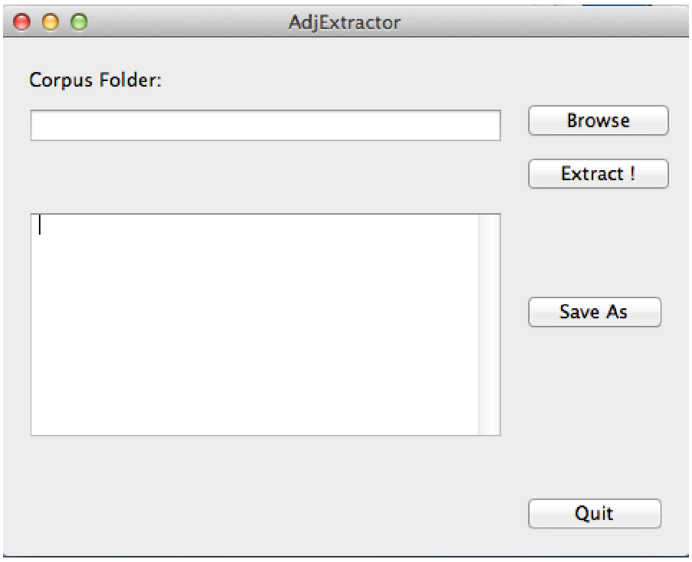


Figure D.1 Interface of adjective extractor

APPENDIX E   TF-DF STATISTICS

TF and DF are calculated as

$$TF_{ij} = \frac{fij}{\sum f_{kj}} \quad (k = 1, 2, \ldots, m) \qquad \text{(E.1)}$$

Where *t* is the term (adjective), *f* is the number of times a term appears in a document, *i, k,* and *m* are the indexes of terms, and *j, n* is the indexes of documents. Given a term t_i and a document d_j, the corresponding TF_{ij} is equal to the number of times a certain term occurs in the document f_{ij} divided by the sum of all terms found in the same document, i.e.,

$$IDF = \log \frac{|D|}{|\{j; t_i \in d_j\}|} \quad (k = 1, 2, \ldots, n) \qquad \text{(E.2)}$$

$$DF = \frac{1}{IDF} \qquad \text{(E.3)}$$

Given a term t_i, the corresponding IDF_{ij} is equal to the total number of documents divided by the number of documents containing this term, and then taking the logarithm of that quotient. In the above expression, $t_i \in d_k$ indicates that the term t_i is found in the document d_k.

APPENDIX F AGGREGATION PROCESS

The code for running the aggregation process can be accessed at http://homepage.usask.ca/~yuz703/.

1. Determine the initial weight of expert for the expert group decision-making

The initial weight is denoted as w_n^1. Where w_n is the weight of *n*th expert, w^1 is the first iteration for the weight. It is noted that

$$w_1^1 + w_2^1 + \cdots + w_n^1 = 1 \quad \text{(F.1)}$$

Step 1: Introduction of d_{ij}. It represents the dissimilarity of decision-making between expert *i* and expert *j*.

$$d_{ij} = |x_i - x_j| \quad \text{(F.2)}$$

Where x_i and x_j denote the ranking made by *ith* expert and *jth* expert.

Step 2: Introduction of s_{ij}. It represents the similarity of the ranking made by expert *i* and expert *j*.

$$s_{ij} = \frac{1}{e^{d_{ij}}} \quad \text{(F.3)}$$

Step 3: Calculation of the initial weight w_n^1.

$$w_1^1 = \frac{\sum_1^n s_{1j}}{\sum_1^n \sum_1^n s_{ij}} \quad \text{(F.4)}$$

$$w_2^1 = \frac{\sum_1^n s_{2j}}{\sum_1^n \sum_1^n s_{ij}} \quad \text{(F.5)}$$

……

$$w_n^1 = \frac{\sum_1^n s_{nj}}{\sum_1^n \sum_1^n s_{ij}} \quad \text{(F.6)}$$

2. Determination of an expert's weight at *k* iteration, denoted as w^k

Step 1: Introduction of the dissimilarity (d_i) between x_i and x^k. x^k denotes the ranking made by the group of experts at the *kth* iteration.

$$d_i^k = \left|x_i - x^{k-1}\right| \quad \text{(F.7)}$$

Step 2: Introduction of the similarity (S_i). S_i indicates the similarity between x_i and x^k, i.e.,

$$s_i = \frac{1}{e^{d_i}} \quad \text{(F.8)}$$

Step 3: Calculation of w_i^k with the assumed equation

$$w_i^k = \frac{s_i}{\sum_1^n s_n} \quad \text{(F.9)}$$

Step 4: Calculation of x^k with the assumed equation

$$x^k = f^k(x_1, x_2, \dots, x_n) = \sum_1^n w_n^k x_n \quad \text{(F.10)}$$

Step 5: Stop an iteration.

When $|x^n - x^{n-1}| < \varepsilon$ or

$\sqrt{(w_1^n - w_1^{n-1})^2 + (w_2^n - w_2^{n-1})^2 + \cdots + (w_n^n - w_n^{n-1})^2} < \varepsilon$,

the iteration stops (ε is usually chosen to be less than 10^{-5}).

APPENDIX G VALUE OF ADPS

Table G.1 Value of ADPs

Item	Value range	Low	Medium	High
Hue	0-359	60	180	300
Saturation	0-255	42	128	213
Value	0-255	42	128	213
Stretch	64-147	64	105	147
Bending	15-180	15	107	180
Buckling	28-99	28	63	99
Damping	1-10	1	5	10
Density	27-50	27	38	50
Shoulder	35-41	35	38	41
Waist	66-80	66	73	80
Hem	90-310	90	200	310

APPENDIX H CERTIFICATE OF APPROVAL FROM BEHAVIOURAL RESEARCH ETHICS

UNIVERSITY OF SASKATCHEWAN

Behavioural Research Ethics

Certificate of Approval

PRINCIPAL INVESTIGATOR
Chris Zhang

DEPARTMENT
Mechanical Engineering

BEH#
14-340

INSTITUTION(S) WHERE RESEARCH WILL BE CONDUCTED
University of Saskatchewan

STUDENT RESEARCHER(S)
Yu Zhao

FUNDER(S)
INTERNALLY FUNDED

TITLE
Research on Relationship Between Human's Feeling and Apparel Design Parameters

ORIGINAL REVIEW DATE	APPROVAL ON	APPROVAL OF:	EXPIRY DATE
19-Sep-2014	22-Sep-2014	APPLICATION FOR BEHAVIOURAL RESEARCH ETHICS REVIEW INVITATION TO PARTICIPATE PARTICIPANT CONSENT FORM SURVEY	21-Sep-2015

Full Board Meeting ☐

Delegated Review ☒

CERTIFICATION

The University of Saskatchewan Behavioural Research Ethics Board has reviewed the above-named research project. The proposal was found to be acceptable on ethical grounds. The principal investigator has the responsibility for any other administrative or regulatory approvals that may pertain to this research project, and for ensuring that the authorized research is carried out according to the conditions outlined in the original protocol submitted for ethics review. This Certificate of Approval is valid for the above time period provided there is no change in experimental protocol or consent process or documents.

Any significant changes to your proposed method, or your consent and recruitment procedures should be reported to the Chair for Research Ethics Board consideration in advance of its implementation.

ONGOING REVIEW REQUIREMENTS

In order to receive annual renewal, a status report must be submitted to the REB Chair for Board consideration within one month of the current expiry date each year the study remains open, and upon study completion. Please refer to the following website for further instructions: http://www.usask.ca/research/ethics_review/

Beth Bilson, Chair
University of Saskatchewan
Behavioural Research Ethics Board

Please send all correspondence to:

Research Ethics Office
University of Saskatchewan
Box 5000 RPO University, 1602-110 Gymnasium Place
Saskatoon SK S7N 4J8
Telephone: (306) 966-2975 Fax: (306) 966-2069

Figure H.1 Certificate of approval

APPENDIX I LIST OF PUBLICATIONS

Zhao, Y., Montazeri, A., Wang, C., & Zhang, W. J., On development of methods for expressing customer affective response for apparel products, Proc. CAD'15, London, UK, 2015, 315-320.

Zhao, Y., Dai, F., Gupta, M. M. & Zhang, W. J., On conceptual modeling of apparel products, Proc. CAD'15, London, UK, 2015, 237-242.

Zhao, Y., He, D., & Zhang, W. J., Toward a systematic design process for apparel product, IMCE, Houston, USA, Nov. 13-19, 2015 (to appear).

Zhao, Y., Dai, F., Gupta, M. M. & Zhang, W. J., Ontology Modeling for Intelligent Computer-Aided Design of Apparel Products, Int. J. of Automation Technology, 2015. Vol. 10. No. 2, 144-152.

Zhao, Y., Sun, J., Gupta, M. M., Moody, W., Laverty, W. H., & Zhang, W. J., 2015. On Mapping from Affective Words to Design Parameters for Apparel Design. Textile Researched Journal (submitted).