CREATION OF COLOUR-CHANGING SMART HOME TEXTILES VIA INNOVATIVE JACQUARD WEAVING TECHNOLOGY

WU WING YAN, GLORIA

Ph.D

The Hong Kong Polytechnic University

2016

The Hong Kong Polytechnic University
Institute of Textiles and Clothing

CREATION OF COLOUR-CHANGING SMART HOME TEXTILES VIA INNOVATIVE JACQUARD WEAVING TECHNOLOGY

WU WING YAN, GLORIA

A thesis submitted in partial fulfillment of
the requirements for the degree of Doctor of Philosophy

AUGUST 2015

CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written nor material which has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

WU Wing Yan, Gloria

ABSTRACT

Recent studies have pointed out that there are technological barriers for developing smart textiles, such as the lack of industry standards that is hampering communication and technological progress. It shows that a common set of standards defining methodologies, specifications and best practices for various smart textiles applications and products is needed. The concerns of being user friendly and easy to handle are very important for both technological and social factors. This signifies that there is a need to develop the related factors of smart textiles products including reliability, energy efficiency, and usability of technical devices even for “non-technical” people, configuration, human friendly and very simple communication protocols. All these show the needs of better development in smart home textiles, especially the light emitting textile for fashion and textile related products.

The practice-based research methodology was adopted in this research study. This study combined the theories of colour-changing and weaving technologies, practical concept development in creating high value interior home textiles products including “smart sofa cloth, curtain, dining table cloth, glass mat and lamp cover” that could fit into the current interior and home textiles market. The research design of this study was divided into five major stages: the “research stage”, “analysis stage”, “design of initial prototypes”, “evaluation stage”, and “detail design” in order to create the high value colour-changing smart home textiles prototypes that could correspond to both human and environmental factors.

The theoretical design process model of colour-changing smart home textiles was developed and based on the concept of French’s design process model as well as the adoption of product development process and engineering approach to industrial design. The main process was detailed as follows: a) identifying needs; b) analysis of problem; conceptual design; embodiment of schemes; c) detailing. The final colour changing smart home textiles prototypes were then created according to the developed design process model.

From this study, the knowledge of colour-changing smart home textiles from the aesthetic and functional perspectives can be enhanced and provide novelty in the contemporary textile design industry. The proposed design process model of colour-changing smart home textiles is able to illustrate the innovative design development for contemporary interior home textiles. The developed high value colour-changing smart home textiles prototypes are able to br utilises in different types of textiles products so as to meet the challenging needs of future lifestyle and consumer requirements. Both of the textile design industry and, fashion and textile design education can be profited because of the theoretical and practical contributions made in this study.

PUBLICATIONS

Juried Exhibition

Wu, G., Au, J., Ho, C.P., & Lam, J. Creation of Colour-changing Smart Home Textiles via Innovative Jacquard Weaving. *Smart Textiles Salon 2015*, *Museum of Industrial Archaeology and Textiles*, *Ghent*, *Belgium* (Juried). Date: 24 – 25 Jun 2015.

Referred Conference Paper

Wu, G., Au, J., Ho, C.P., & Lam, J. Development of Theoretical Design Process Model for Smart Home Textiles. *Proceedings (CD-ROM). The 12th Asian Textile Conference, Shanghai*. Date: 23 – 26 Oct 2013.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my chief supervisor, Dr. Joe Au for his support and guidance throughout the research, without his professional advice and encouragement, I would not have been able to complete this thesis.

In particular, I would like to express my heartfelt thanks to my loving family, who always gives support whenever I need.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

As technological products are growing rapidly in the market, companies and sales are rushing to promote their new products in order to raise and maintain their profits. Sales and buyers also become very competitive because everyone wants to have their own high-tech and functional products. However, the aesthetics, functionality and performance of product play an important role when customers are willing to buy a product that is worth spending many on it. “Products that win will be those that enhance the quality of life in some way, and have added value in terms of functionality and performance” Baurley (2004, p.274). Besides, the market has been boosted by changes in consumers’ lifestyles. In order to meet the challenging needs of future lifestyle and consumer requirements, high-tech fabrics must continue to cross the boundary into everyday fashion apparel as well as into home interior furnishings. “The integration of smart functionality into clothing and other textile products will fundamentally change cultures of clothing and interior products” Baurley (2004, p.274).

Products have always engendered some kinds of sensorial qualities such as our senses of sight, touch, sound, taste and smell. Those stimuli form our experiences from our environment. Intelligent materials will provide a new array of sensorial qualities, which will impact both on how we experience our surroundings and how we interact with them. Also, it will improve our control over our material environment and facilitate our creative interaction with it as we seek to be co-creators with tailoring experiences corresponding to our various moods. Watkins

(2005) stated that those wearable electronic products look very technical rather than a garment as most of them are designed and developed by engineers. This indicated that designers should also consider the look of the design to meet consumers' needs. For example, referring to the IMI and the EPSRC Smart Textiles Network report in 2006, light emitting and colour-changing textiles will allow people to be creative and expressive in new ways. Devices such as sensors are often used to obtain information, for instances, environmental sensors, physiological function sensors, antennae, global positioning-system receivers, and camera and sound sensors. "The information needs to be processed somehow by the wearer. An interface is a suitable medium for transacting information between devices and the wearer as well as between the wearer and outside world" (Tao, 2005, p.3).

1.1.1 Need of Home Textiles

The horizon of business adoption for smart textiles is shown in Figure 1. It indicates that a major potential opportunity exists in clothing as well as interior textiles (Schwarz, et al., 2010). "Several organizations forecasted the market development of smart textiles, which, according to Delphi study report, is supposed to grow rapidly" (Schwarz, et al., 2010, p.133). The study also forecasted that an increasing demand on smart textiles is expected for the healthcare and the communication entertainment markets (Schwarz, et al., 2010). The researchers also pointed out that there are technological barriers, such as the lack of industry standards that is hampering communication and technological progress. It shows that a common set of standards defining methodologies, specifications and best practices

Figure 1: Horizon of business adoption

for various smart textiles applications and products is needed. Besides, researchers pointed out that their reliabilities are insufficient in some of the smart textile products that fail to react or function in a normal manner. It indicated that the concerns of being user friendly and easy to handle are very important for both technological and social factors. This signifies that there is a need to develop the related factors of smart textiles products including reliability, energy efficiency, and usability of technical devices even for “non-technical” people, configuration, friendly human and a very simple communication protocols. Schwarz, et al., (2010, p.163) stated that “the further developments using smart material such as photochromics and thermochromics may offer added value because these materials have the ability to control light, temperature and colour”. Furthermore, the experts have pointed out that presently the service system to maintain smart interior textiles is insufficient. All these show the needs for better development in smart home textiles, especially the light emitting textile for fashion and textiles. Schwarz, et al., (2010) pointed out that colour-changing smart textiles are currently an open space for development with such demanding needs.

1.1.2 Definition of Smart Textiles

According to Schwarz, et al., (2010, p.107) definition of smart material, “intelligent materials and systems are capable to sense and respond to their surrounding environment in a predictable and useful manner”. Smart materials like thermochromic materials are developed for changing their colours in response to the changes in temperatures. Figure1-2 shows the concept of a smart textile system that can sense its environment, act upon it and

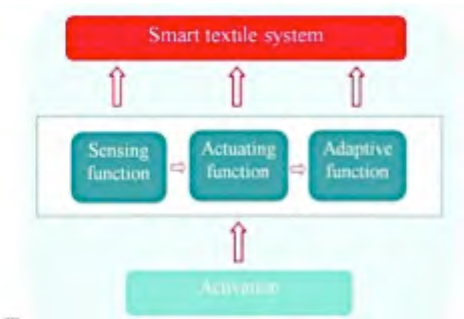


Figure 1-2: Smart textile system

adapt its behaviour to it.

Textiles with a sensing function are referred to as passive smart textiles. Textiles with an actuating function are described as active smart textiles as they sense a stimulus from the environment and also act on it. Textiles with an adaptive function are called very smart textiles as they take a step further and have the gift to adapt their behaviour to the circumstances.

1.1.3 Definition of Colour-changing Smart Home Textiles

In this research study, the colour-changing textile is defined as smart material for home textile. This will allow people to be creative by applying this material into home textile with innovative jacquard weaving techniques. Thus, the proposed colour-changing smart home textiles are able to bring both entertainments and communications to fulfil the future needs of the market.

1.2 Problem Statement

This practice-based research study combined the theories of colour-changing and weaving technologies, practical concept development in creating high value interior home textile design. An interior based smart home textile prototypes were finally created. By reviewing the latest illuminative and colour-changing interior, fashion and accessories products in the market and those applications in visual expressions, the technologies that helped to realise a conceptual experience involving jacquard weaving technologies were identified as the technology of illumination, the application of various sensors and devices that could be integrated into home textile, and the specific circuit design suitable for interior textiles.

1.3 Aim and Objectives

This project aimed to create colour-changing smart home textiles via innovative jacquard weaving technology and the specific objectives are as follows:

- to study the up-to-date design products of smart home textiles;
- to investigate the technologies and applications of various colour-changing materials such as photochromic, that could be integrated into smart home textiles;
- to investigate how colour-changing materials can be integrated with the jacquard weaving technology for developing smart home textiles;
- to develop the theoretical design process model of colour-changing smart home textiles;
- to create and assess various colour-changing smart home textiles prototypes developed by innovative jacquard weaving;
- to finalise a detailed design specifications for colour changing smart home textiles prototypes; and
- to create high value colour-changing smart home textiles prototypes including "smart sofa cloth, curtain, dining table cloth, glass mat and lamp cover" that could present and fit into the current interior and home textiles market.

1.4 Research Methodology

The practice-based research methodology was adopted in this research study. The prototyping of colour-changing smart home textiles was the main focus. In this study, the research design was divided in five major stages: the "research stage", "analysis stage”, “design of initial prototypes”, “evaluation stage”, and “detail design” in order to create the high value colour changing smart home textile prototypes that could correspond to both human and environmental factors.

The literature research was concentrated on up-to-date smart textile products in interior home textiles. The technologies and applications of various colour-changing materials that could be integrated into smart home textiles were further investigated. The applications of different colour-changing materials that could be applied on jacquard weaving technology for developing smart home textiles were also be studied.

The theoretical design process model of colour-changing smart home textiles was developed based on the concept of French’s design process model as well as the adoption of product development process and engineering approach to industrial design. The main process was detailed as follows: a) identifying needs; b) analysis of the problem; conceptual design; embodiment of schemes; c) detailing. The final colour changing smart home textiles prototypes including “smart sofa cloth, curtain, dining table cloth, glass mat and lamp cover” were then created according to this developed design process model.

1.5 Significance of Study

From this study, the knowledge of colour-changing smart home textiles from the aesthetic and functional perspectives can be enhanced and provide novelty in the contemporary textile design industry. The proposed design process model of colour-changing smart home textiles is able to illustrate the innovative design development for contemporary interior home textiles. The developed high value colour-changing smart home textiles prototypes are able to utilise in different types of textiles products so as to meet the challenging needs of future lifestyle and consumer requirements. Both of the textile design industry and, fashion and textile design education can be profited because of the theoretical and practical contributions made in this study.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Introduction

The illuminated and colour-changing products including fashion, textiles and accessory designs, as well as the latest technologies and applications were reviewed in this chapter. This chapter also covers the following topics: (i) various illuminative materials – light-emitting diodes, organic light-emitting diodes and optical fibre; (ii) various sensors – sound, heat, humidity, pressure sensor; and (iii) technologies and process in weaving setting up instructions for hand loom and jacquard machine, screen printing of conductive inks, and embroidery of conductive threads. The research gaps were then explored and identified for this research study.

2.2 Current Products of Smart Home Textiles

There are examples of current smart home textile products adopting colour-changing materials. The current smart home textiles products include pillows, cushions, curtains, carpets, decorations and sofas. It has shown an increasing demand of colour-changing products in the market. "Specific applications maybe categorised as positively beneficial, useful or just nice to have. For examples, the use of smart textiles to provide thermal control, including air conditioning like heating and cooling and the control of solar radiation by the use of curtains would be beneficial in a variety of domestic, office and communal space environments" (Schwarz et al., 2010, p.163). Moreover, as the smart materials like photochromics and thermochromics have the ability to control light, temperature and colour, they have shown a positive benefits in energy efficiency, fashion and mood control (Schwarz et al., 2010).

2.2.1 Pillow Alarm

Seung Jun Jeong who is a Korean designer, developed a 'Pillow Alarm' with sensible functionality, combing soft materials with 'hardware-made-soft'. This 'Alarm Pillow' will start vibrating at a pre-set time, just like an alarm clock. The idea is that when couples sleep at the same bed, there is usually a problem which one has to wake up earlier than the other. With its vibration function from a specific pillow, it can wake the one who needs to wake up on pre-set time without disturbing their partner (Seung, 2010).

Figure 2-1: Pillow Alarm

2.2.2 Pillow Remote Control

It is an interactive pillow with soft technology with a universal remote control and is able to talk to over 500 devices. Customers can hug the remote and sleep on it, its idea is to allow the user to hug or sleep on the pillow and it is large enough not to misplace it. Also, it has a power-saving auto shut-off feature which puts the remote functions into deep sleep after 60 seconds of inactivity. The design inspirations of this 'Pillow Remote Control' have shown up for many years as DIY enthusiasts and designers have been successful to give a soft touch on smart textiles (Hilhorst & Zambetti, 2007).


Figure 2-2: Pillow Remote Control

2.2.3 Magical Illumination of Carpet

A Dutch designer, Dorith Sjardijn's takes traditional crafts like carpet weaving and upgrades it with 21st century technology. The example is using tufting electroluminescence wires into a Persian rug and cracks of light along the woven pattern are created. Its design work is simple to make and has strong aesthetic and emotional value (Sjardijn , 2010).

Figure 2-3: Magical Illumination of Carpet

2.2.4 Colour-changing Moonlight Cushion

The design example on the right shows the 'Colour changing Moonlight Cushion' which was designed by an U.K online store called Find-me-a-gift. The idea of this design is to bring some relaxing, soft colours into living room and cheers people up. Its design is very decorative, by using illuminated colour changing techniques which are taking the interactivity one notch up on the interactive textile scale, the colour changes when the cushion is stroked (Findmeagift Ltd, 2010).

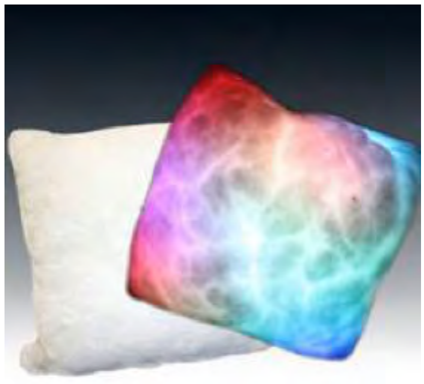


Figure 2-4: Colour-changing Moonlight Cushion

2.2.5 BMW Smart Fabrics

Figure 2-5: BMW Smart Fabrics

The German based BMW is very serious to replace the textile surface for the car interior with comfortable smart fabrics that can sense the car occupants and also serve as an interaction point with the car to accept our swiping gestures. BMW has picked up the idea from the researchers at the Polytechnic School in Montreal, Canada. A soft polymer-based fibre is woven into fabrics and the electrical properties of fibres change depending on the location where it is touched, and this sensing fibre can be easily cleaned too (BMW, 2011). Furthermore, the car industry is more aggressive and active when it comes to innovation. Research and development budgets in the car industry are substantially higher compared to the textile and clothing industry (Zainzinger, 2012).

2.2.6 LED Cell Carpet

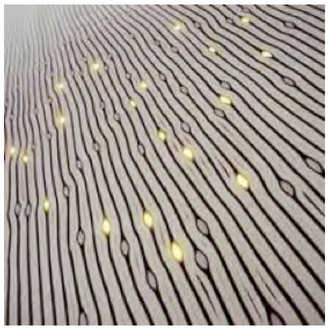


Figure 2-6: LED Cell Carpet

One of the carpet design groups in the Netherland's called LAMA Concept has created the 'LED Cell Carpet' which is made from pure wool felt strips with embedded LEDs that blend perfectly into the carpet design. The designers, Yvonne Laurysen and Erik Mantel combined felt and LEDs to create a flexible carpet design. The material use is 100% pure wool felt which is pressed and cut into strings in order to make a natural product that is non-flammable, soundproofing and water-repellent. This unique design in form of felt strings can be beneficial to make rugs of any size. Also, there is no need to replace the whole carpet when any damage happens as customers can simply replace the string (Laurysen &

Mantel, 2009).

2.2.7 Fiber Optic Tapestry

Figure 2-7: Fiber Optic

Ligorano and Reese (2012) stated that weaving illuminated fabric using fibre-optic strands can achieve mesmerizing light effects on clothing, accessories and pillows. The artists, Nora Ligorano and Marshall Reese picked up the unique optical property of woven fibre optic light and transformed tapestry. In this design, it shows how fibre-optic strands transfer light from one end of the strand straight out at the other end without losing much of its light intensity. On the contrary, when the fibre-optic strand is artificially damaged along the outside skin of the strand, some light rays escape and create the distinctive, soft, and almost mystical glow.

2.2.8 Colour-changing Textile

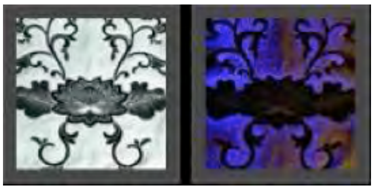


Figure 2-8: Colour-changing Textile

Figure 2-8 shows an example of textile design fabric that can change colour under sunlight (Schicker, 2009d). They are white until they are exposed to sunlight, when colour and pattern are magically revealed. A range of products for interiors, including backdrops, cushions and upholstery fabrics that constantly respond to the natural environment and interact with the changing light of the days are created (Schicker, 2009e).

2.2.9 Solar Energy Curtain

Figure 2-9: Solar Energy Curtain

Due to the fact that textiles and technology continue to be blurred, many designers, architects and scientists are probing new ways of making the invisible visible (Wagner, 2009). The Interactive Design Institute in Sweden carried out a project called, 'The Energy Curtain' in 2010. The curtain is able to absorb sun energy during the day and releases it in the form of light in the evening. The curtain collected the energy from the sun and the inside area of the shade shows a glowing pattern. This curtain is woven from a combination of textile, solar-collection and light-emitting materials **(**Ernevi et al., 2012).

2.2.10 Luminous Carpet

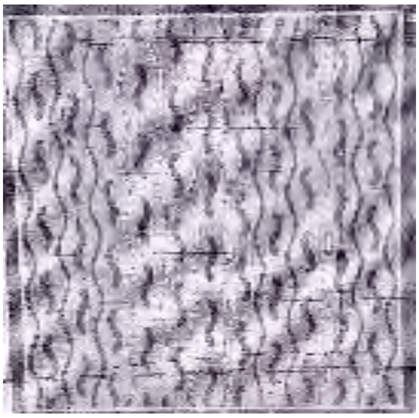


Figure 2-10: Luminous Carpet

The 'Luminous Carpet' is equipped with pressure sensors and light emitting fibre developed by the Belgian-based Centexbel. The floor carpet detects the presence, location and displacement of people on the carpet and it can switch on the light when someone gets out of bed. If someone lies on the carpet for a defined period of time, a remote emergency service gets alerts. The luminescent waves are turned on and off depending on the location and the displacement of the person on the carpet (Schwarz, et al., 2010).

2.2.11 Charging-up Smart Fabrics with a Woven Battery

Figure 2-11: Charging-up Smart Fabrics with Woven Battery

A team of scientists at the Polytechnic School of Montreal, Canada has investigated how electrical power can be charged into our smart wardrobe. They have tried to use a type of Li-Ion battery chemistry which is not based on the usual liquid electrolytes but made of solid thermoplastic sheets of lithium iron phosphate cathodes with lithium titanium anodes sandwiched between solid polyethylene oxide electrodes. Then, strips cut from the sheet are woven into fabrics and an electrical power storage capability into textiles can be integrated. The battery strips have the consistency and feel of leather that can make it useful for certain types of fabrics to blend into them seamlessly. But, the main issue on how the woven battery can be waterproof requires further investigation (Liu, et al., 2012).

2.2.12 Photonic Textile

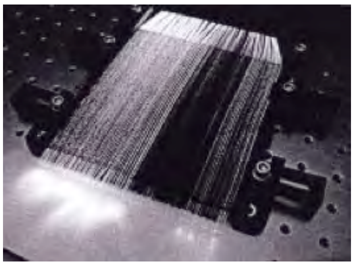


Figure 2-12: Photonic Textile

An example of smart textile was presented in the Photonic Textiles Workshop. Skorobogatiy and Schicker (2009f) from the University of Montreal and Central Saint Martin's College of Art and Design aimed to develop light emitting-textiles from an exciting new generation of optic crystal fibres developed at the University of Montreal. "It has been shown that all plastic photonic-bandgap fibres (PBG), designed to have leaking guided modes, also have great potential for making colour-tunable photonic textiles, thus enriching the functionality of optical fibres"

(Won, 2008, p.650). It is a material that is highly advantageous for illumination applications because photonic bandgap has its effect to guide light in the low refractive index core for photonic bandgap and it emits a portion of colour on sideways. “Bragg fibres that reflect one colour when side illuminated, and emit another colour while transmitting the light” (Won, 2008, p.650). Skorobogatiy and Schicker (2009) demonstrated that it shows a stability result when PBG fibres emitted colour over time to photonic textiles. Furthermore, it has good potential in distributed sensing and high bandwidth telecommunications with multimode fibres”. Won (2008, p.650) also stated that “these textiles could be useful for producing interactive cloth, sensing fabrics, dynamic signs and art”.

2.3 Related Studies of Colour-changing Fashion and Accessory Design

Smart fabrics had developed in the early 1990s, with huge evolution in technology and application, and a number of products on the market (Schicker, 2009d). There are examples of fashion products adopting commercial smart fabrics to integrate wearable technology for communication and entertainment, heating and body temperature control, generating energy through solar cells, and light-emitting fabrics.

2.3.1 Schoeller's Jacket under Light

Figure 2-13: Schoeller's Jacket

The Switzerland-based technology company called Schoeller has developed a durable, high-tensile fabric with glow-in-the dark effect. The fabric features are 3D mesh structure which is woven with special yarn. When it is exposed to light, it absorbs and then glows when it is dark. The fabric can be used and applied to interior design products like room dividers, also in safety-related applications like shoes or for work protection. In June, 2009, this fabric won a Design Plus Award during the Materials Vision trade fair, held in Frankfurt as a successful design featuring a combination of innovative materials and intelligent functionality (Schoeller, 2009).

2.3.2 Zegna Sport Freeway Jacket

Figure 2-14: Zegna Sport Freeway Jacket

This 'Sport Freeway Jacket' is designed by Grungy Gentleman. He simply creates a winter collection that provides seamless transition from the office to the slopes. This jacket is water repellent and breathable enough to meet customer riding standard. When it gets dark outside, there is a controller in your pocket to activate the LED lights that runs from the top of each side down to your waist. The best part is that you can keep lights off and to wear it over a suit in wintertime (Schicker, 2009a).

2.3.3 Illuminative Colour-changing Dress

Figure 2-15: Illuminative Colour-changing

CuteCircuit is an internationally well-known fashion house and it has been pushing the boundaries of wearable technology since its launch in 2004 (Rosella & Genz, 2010). "It has designed four spectacular jackets for the Worldwide 360º Tour of the legendary rock band U2. Lights that are individually synchronised and capable to recreate any number of dynamic displays, patterns and even video in real time and wirelessly controlled by the lighting design team using 'Q', the live performance software for wearable technology by CuteCircuit " (Rosella & Genz, 2010). The white and black leather jackets have hand embedded over 5,000 LEDs. The designers have considered every single detail when designing this U2 Jacket. Rosella and Genz (2010) indicated that the look of it does not change much and it is still like a beautiful leather jackets after integrated such applications on it. It is because there are no wires in the system and the circuitry is able to be flat against the fabric, also the lights escape through thousands of small apertures in the jackets.

2.3.4 Embrace-me Hoodie

The Embrace-me Hoodie is a dark-blue canvas hoodie and its content is cashmere-like 100% bamboo basket weave. In this collection, the logo is created with a pattern that is made of a futuristic silver conductive fabric. The power will connect through that pattern when two people wearing the hoodies embrace. The embrace is then transferred into light and sound afterwards. The small white lights at the back flicker and it forms a big-dipper pattern with a faint heart beat sound at the same time. The design inspiration of the hoodie is from the construction of early Siberian hooded coats, it creates an enveloping safe haven and a tranquil vestige of protection and romanticism (Scaturro, 2009).

Figure 2-16: Embrace-me Hoodie

2.3.5 Photonic Textiles by Karma Chameleon

Karma Chameleon has developed the interactive electonic garments constructed by a new generation of composite fibres. It is able to harness power directly from the human body. It can store human natural energy and use it to change its own visual properties. On the right figure, it shows how illuminative fibre optics creates when the composite fibres are woven into fabrics and are integrated into clothing (Sayed, Berzowska & Skorobogatiy, 2010).

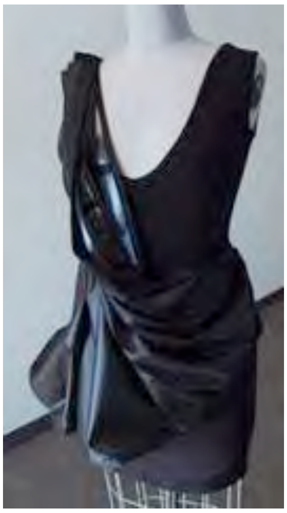


Figure 2-17: Photonic Textiles by Karma Chameleon

2.3.6 GER–Emotional Fashion


Figure 2-18: GER-Emotional Fashion

Kristin Neidlinger, a designer with focus on sensory computer interface, designed an outfit called GER which stands for 'Galvanic Extimacy Responder'. Its function is to detect the emotional or stress level via the electrical conductivity changes on the human skin. If people are nervous or get excited, their sweat secretion will increase and the conductivity of the sweaty skin surface increases. Neidlinger integrated such sensors into clothing and translates the skin resistance values into light patterns, thus parts of the clothing are illuminated and the emotions of the wearer are visualised (Neidlinger, 2010).

2.3.7 Show of Light


Figure 2-19: Show of Light

Marina Polakoff, the fashion designer and interactive technologies enthusiast who creates costumes for music and dance shows. The dress interacts with music, voice and movements, blending the appearance of the dress with the acoustic dimension of the performer. The dress contains hundreds of mini LEDs, integrated into the fabric to diffuse the high bright LEDs for a softer, more natural appearance. The intensity, colour and light effects on the dress are controlled by the surrounding sound and movements and translated into lighting effects ranging from very subtle to highly dramatic colours shown on the costume (Polakoff, 2010)**.**

2.3.8 Haute Tech LED-coat

The Dutch designer, Wendy Legro has used LED light in designing a coat. Its feature is that when people are wearing it and moving around, the folded area will be opened and closed, the LED lights will also turn on between the folds. She mentioned that by adding light elements to clothing will help to balance between the look, such as loud shouting light flashes and soft sophistication fashion design. Her idea is to combine both LED lights and fashion design elemnts to make the coat covering with colourful lighting effects (Legro, 2010).

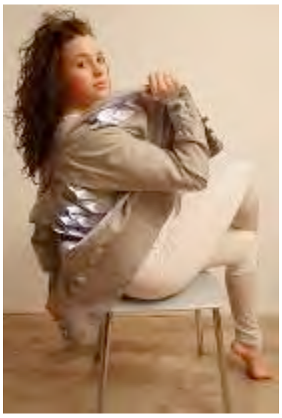


Figure 2-20: Haute Tech LED-coat

2.3.9 Liquid Iridescence–Structural Colour Fashion

In Figure 2-21, it shows the Amy Winter's new collection of colour shifting designs. She creates amazing colour changes fashion pieces with a new fibre technology. She uses a new type of fabric called 'Polymer Opal' lycra. It is rubber-like and its fibre properties result in colour changes when the fabric is bended, stretched or twisted. It does not need battery power, but only by the dynamic movement of the body. The colour shades are activated by the body movement in order to create colour changes. In her collection, she skilfully fuses science with fashion by using 'structural colour'. It is a type of colour generated through diffraction exhibiting a metallic look even though it usually contains no metal. Structural colours can be found in tropical fish, in the wings of tropical butterflies, beetle wings, oil slicks and soap bubbles (Konstanze, 2013).

Figure 2-21: Liquid Iridescence-Structural Colour Fashion

2.3.10 Sound Illuminating Dress

The 'Sound Illuminating Dress' on the right shows a beautiful dress made by Chung-Hay Luk and presented at the eTextile and Wearable Computing Showcase. It is a cleverly designed strapless dress which made the technology to be involved into part of the style decision. In Figure 2-22, it shows part of the dress stays in dark fabric and the other part containing electroluminescent wire at the seam. The seam is made from light white colour which wraps in an irregular shape around the front. The light effect is activated by ambient sound picked up from a microphone (Luk, 2011).

Figure 2-22: Sound Illuminating Dress

2.3.11 Fractal Living Jewellery

The team at Philip Design has sent out provocations to question and influence the world of electronics, fashion and textile design. 'Fractal' is a living jewellery suits that changes in response to the wearers behaviour and mood. The opacity, colour-change and light-intensity emitted from each of the 'Fractal' jewels almost become an extension of the body itself, responding to activity and use (Wagner, 2008).

Figure 2-23: Fractal Living

2.3.12 Illuminated Work Gloves

A gloves company has brought illuminated gloves down to the real world in form of work gloves. It brings convenience to customers and they do not have to keep on instructing to hold the flash light at the spot where you need to see. With this multi-purpose mechanics gloves with LED lights, it gives enough options to have the light beam at the right spot, especially for customers who do occasional repairs on cars, bikes or around the house know that during the dark a third hand is required to hold a flash light. There are LED lights with four attachment points on each glove and there are two lights per pair (MCR Safety, 1996).

Figure 2-24: Illuminated Work

2.3.13 Puma Basket CC sneakers

This Puma Basket CC sneaker has applied smart textiles in the design. Matthias Hartmann, who is the Director of Strategic Projects Guest Service at Deutsche Bahn AG, currently has helped to back up the smart fabric for the commercial sport application. The Basket "CC" stands for colour change. The sneaker utilises a special heat sensitive material called thermochromic ink to change colour which responses to the heat of your foot and the environment. The fabric features a reptile skin-like pattern and the shades of the sneaker go from olive brown to dark green, to dark blue to deep purple. When the temperature is below zero celsius, the sneaker turns to black (Schicker, 2009b).

Figure 2-25: Puma Basket CC sneakers

2.3.14 Socks with incorporated Heating System

Canesis Limited has developed a heating system comprised of textile based materials. This system feels and drapes like a conventional textile and it is durable and washable (Anderson, 2005). Figure 2-26 shows the heating system incorporated in to socks. This material is currently used as interior products such as upholstery and blankets.

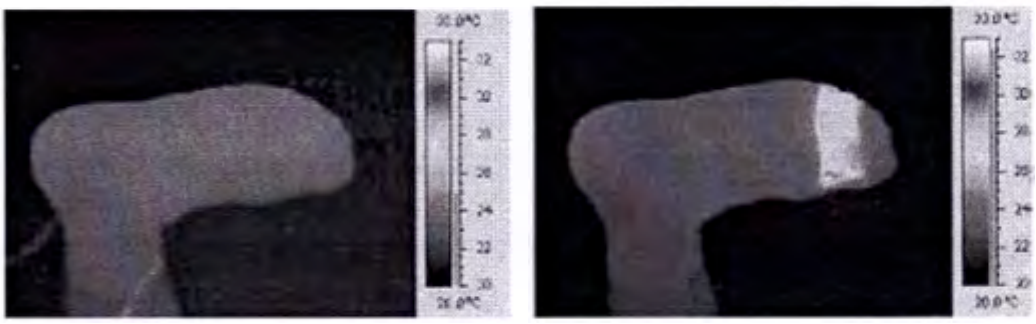


Figure 2-26: Socks with incorporated Heating System

2.4 Advantages of Colour-changing Technology

Colour-changing material is identified as a smart material from research in many different fields. The colour-changing textile application is manifold, one example of the colour-changing material called thermochromic changes its colour when it senses the changes in temperature (Schwarz et al., 2010).

The colour-changing smart material has been widely used in the interior market and it has become an important component in design field (Schwarz et al., 2010). For example, light is one of the smart materials which stimuli our sense of sight. Refer to the literature review in this chapter, various colour-changing technologies have been applied in interior textiles, fashion and accessory products.

Lighting is one of the smart textiles which have already found their way into a number of automotive applications. “The automobile sector is a platform that has started to take advantage of smart textiles in different manners” (Schwarz et al., 2010, p.165). The application of LEDs can be integrated into clothing as well as home furnishing and floor coverings. Besides, “polymer LEDs are very promising candidates for future wearable. As they have high contrast, as high level of brightness, require much less power and are flexible” (Tao, 2005, p.4).

2.5 Technologies and Application of Various Illuminative Materials

2.5.1 Light-emitting Diode

A light-emitting diode (LED) is a semiconductor device that emits visible light when an electric current passes through it. The light is not particularly bright, but in most LEDs it is monochromatic, occurring at a single wavelength. LEDs are available in red, orange, amber, yellow, green, blue and white. LEDs are real unsung heroes in the electronics world. They do dozens of different jobs and are found in all kinds of devices. Among other things, they form numbers on digital clocks, transmit information from remote controls, light up watches and tell you when your appliances are turned on. Collected together, they can form images on a jumbo television screen or illuminate a traffic light. Basically, LEDs are just tiny light bulbs that can be fit easily into an electrical circuit. But unlike ordinary incandescent bulbs, they do not have a filament that will burn out, and they do not get especially hot. LEDs are illuminated solely by the movement of electrons in a semiconductor material and they last just as long as a standard transistor. The lifespan of an LED surpasses the short life of an incandescent bulb by thousands of hours. Tiny LEDs are already replacing the tubes that light up LCD HDTVs to make dramatically thinner televisions (Harris & Fanlon, 2011).

2.5.1.1 History of LEDs

Henry J. Round, was one of the British experimenter who made the first light-emitting solid-state diode in 1907. Nick Holonyak was the first inventor of practical LED while he was at General Electric Company in 1962. The first LEDs were red colour and it was available and commercially used in late 1960s. They were replacements for incandescent indicators and in seven-segment displays. It has become one of the expensive equipment in laboratory and electronics test equipment. Later on, it has applied in TVs, radios, telephones, calculators and watches. Its technology has become more advanced that the light output is increased and it is bright enough to be used in illumination. Basically, the LEDs are made in 5mm T1-3/4 and 3mm T1 packages. As high power is needed for application; it is necessary to get rid of the heat. Therefore, a more complex and heat dissipation package has been added into the package. One of the early packages was from Philip

Lumileds and that was a package for state-of-the-art high power LEDs (Anton, 2007).

2.5.1.2 Applications of LEDs

Upon literature review, there are advantages of using LEDs as illuminative purposes and illustrated as follows:

- The light-emitting textiles allow people to be creative and expressive in new ways.
- The application is not limited to clothing, like shirt or jackets; it can also be integrated into home furnishing and floor coverings.
- The LEDs and light sources can be integrated into garments for communication or indication.
- It can also act as a health and safety purposes.

2.5.1.3 Colour-changing Technology in LEDs

"The last few years have seen a huge increase in the transfer of coloured architectural lighting, derived from entertainment and theatre, into the urban and exterior environment" (Gardner, 2005, p.366). According to Gardner (2005), there have been introductions in coloured lighting technology during the last 15 years. LEDs could be used in back lights for thin, flat television screens, computer displays and wristwatch faces. To produce white light, the blue, red and green light needed to be generated. Blue LEDs had become widely available in the late 1990s. Blue LEDs are based on the wide band gap semiconductors gallium nitride and indium gallium nitride. Semiconductors gallium nitride and indium gallium nitride can be added to existing red and green LEDs and to produce the impression of white light. The light emission can be varied from violet to amber by varying the relative InN-GaN fraction in the InGaN quantum. However, these devices are not efficient enough and the technology of blue and green devices is not mature enough. Green LEDs from the InGaN-GaN system are efficient and brighter compare with the green LEDs produced with non-nitride material systems. Today, most ‘white’ LEDs are based on an InGaN-GaN structure for production and they emit blue light of wavelengths between 450 nm to 470 nm blue GaN. Spectrum of a "white" LED clearly showing blue light is directly emitted by the GaN-based LED. The newest method producing white light LEDs uses substances without phosphors based on homoepitaxially grown zinc selenide on a ZnSe substrate which simultaneously emits blue light from its active region and yellow light from the substrate. Michael Bowers, a graduate student at Vanderbilt University in Nashville developed a new technique, involves coating a blue LED with quantum dots that glow white in response to the blue light from the LED to produces a warm and yellowish-white light (Mertens, 2013).

2.5.2 Organic Light-emitting Diode

OLEDs are made from organic, carbon-based materials. They are semiconductors, emitting light when electricity is applied. Comparing to LED point sources, OLED lighting devices are thin panels emitting light across their surface area. The advantages are that OLEDs contain no toxic metals offering more design flexibility than LEDs. Currently, OLEDs are expensive; however future manufacturing technologies will enable cheap, large-size panel production such as ink-jet printing and roll-to-roll printing. OLEDs offer a great picture quality which provide brilliant colours and fast response rate and a wider viewing angle. The basic structure of an OLED is a cathode with an emissive layer and an anode. In order to make them more efficient, modern OLED devices use multi-layer design; however the basic functionality remains the same. Today, the major problem of OLED facing is the price as the cheaper manufacturing processes are not available yet and it leads the making production capacity very limited (Mertens, 2013).

2.5.2.1 History of Organic Light-emitting Diode

There has been a fast progress in OLED technology during the past few years. The OLED technology will play an important role in the future market. Experts have pointed out that there is an expectation of the real market breakthrough around 2014-15. The OSRAM has introduced the first OLED lighting fixture in 2008. One of the lighting designers, Ingo Maurer has used 10 OLED panels for designing a desk lamp whereas OSRAM only used 25. Philips became the first company to offer OLED panels under the Lumiblade brand in 2009. The OEMs have allowed designers to experiment with the new technology with the Lumiblade panels (Mertens, 2013).

2.5.2.2 Applications of Organic Light-emitting Diode

The largest OLED panel on the market today is Lumiotec's 15-by-15 centimeter panel. OLED displays are used mainly in small 2" to 5" displays for mobile devices such as phones, cameras and MP3 players in today market. OLED displays are pricing compare to LCDs, but it offers brighter pictures and better power efficiency. It is an ideal for battery powered gadgets. Samsung and LG are two leading OLED display makers for televisions, tablets, and cell phones and they have gained benefits from it as a lot of the technologies and expertise are shared between OLED displays and lighting panels (Mertens, 2013).

Figure 2-27: Samsung OLED Television

2.5.2.3 Colour-changing Technology in Organic Light-emitting Diode

The feature of OLED technology is that a flat light emitting made by placing a series of organic thin films between two conductors. A bright light will be emitted when electrical is applied. OLEDS are thinner and more efficient than LCD displays and they do not require a backlight as they emit light. They can also be used to make displays and lighting (Mertens, 2013).

In the future, Mertens, (2013) pointed that it can be used to create flexible and even transparent displays and it opens up a whole world of possibilities:

- Curved OLED displays placed on non-flat surfaces
- Wearable OLEDs
- Transparent OLEDs embedded in windows
- OLEDs in windshields of cars
- New designs for lamps

2.5.3 Optical Fibre

According to Harlin et al. (2002), fibre optic systems are used today for lighting, decoration and sign applications. It is thus simple to show different colours of light in a tight screen area when the actual light source that emits heat can be located separately. Some POF systems emit light along the entire cable. Materials that emit visible light through fluorescence or scattering can be added to the fibre. Side-emitting fibres are commonly used in the lighting of architectural and contour buildings, hotels and entertainment centres. In public premises and leisure areas, there is a need for light guides due to complicated routing or limited lighting. Changing particle size and concentration can even control light emission in large core-size 10mm bulky rods of POF. The material is manufactured by means of adding micro-spherical beads during the synthesis of the rods. To a certain extent, illumination fibre material can be added to fabric structures. Weaving the POF into the fabric makes light leak out of the fibre and planar flexible lighting elements can be fabricated.

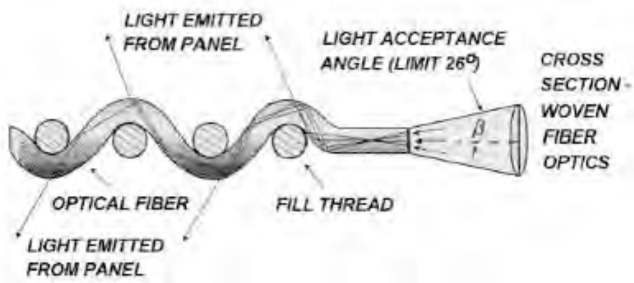


Figure 2-28: Optical Fibre

2.5.3.1 History of Optical Fibre

Today many of these solutions are based on bulky lamp rows or less effective taping assembles. Optical fibre makes it possible to build this function into carpets and such like in a most sophisticated and space-saving manner. Light guide illumination is useful in hazardous and explosive environments. High-voltage tube devices can be replaced with fibre, thick fibre or rods. There are active research studies related to intelligent clothing. The applications combine electronics and information technology with textiles. This began with military applications, but later the solutions have been combined into leisure products and safety clothing.

2.5.3.2 Application of Optical Fibre

The applications of optical fibre as illuminative purposes are as follows:

- It is suitable for novel development of flexible displays based on polymeric light emitting technology and its potential application can be used in smart textiles such as flexible displays, advertising and design.

- Intelligent systems have been improved in recent year and optic fibre is one of the materials that have its improvement in comfort and performance.
- As the fibre colour is coded in its geometry and no colourants or additives are needed and the stability of the emitted colour over time,
- The fibre naturally emits coloured light without the need of mechanical post-processing and it can result a very colourful interference of light.
- By controlling the relative intensities of the ambient and guided light, the overall fibre colour can be varied.

2.5.3.3 Colour-changing Technology in Optical Fibre

"Plastic optic fibre is used for illumination. The main source of the illumination is the core of the fibre that is constructed with cladding, which is nothing but step indexed fibre manufactured in the extrusion process" (Gokarnedhan & Dhanapal, 2007, p.267). The light power transmission or the amount of light power that could be transmitted through an individual optical fibre depends on the optic opening, cross section area, and on the attenuation of the fibre. The acceptance angle of optical fibre is greater than 35 degree, and the core diameter is ranging from 500-1,900um. Intensive light source can be obtained only at the end of the fibre. It is suggested that optical fibre can be woven to produce textile fabrics. However, the weaving speed has to be reduced or fibre had to be warmed during weaving in order to assign the required toughness for the process. The use of polycarbonate yarn as weft presented no problems in jacquard weaving, so it is possible to produce a variety of textile fabrics.

2.5.4 Coating of Colour-changing Material

2.5.4.1 Photochromic Dye

Photochromic dye changes colour when exposed to ultraviolet light usually from the sun or a black light. The inks are effectively colourless indoors and turn into vibrant colours outdoors. When bringing back indoors, the inks become clear again. The inks become intensely coloured after only 15 seconds in direct sunshine and return to clear after about 5 minutes indoors. Its application is perfect for textiles and other applications where there is a period of exposure followed by non-exposure to UV light. A wide range of reversible PC products, from raw materials to finished inks, powders, dyes and finished products is available. On the above, figure 2-29 shows the colour conversion of photochromic dye (New Prismatic Co. LTD, 2008b).

Figure 2-29: Colour Conversation of Photochromic Dye

2.5.4.1.2 Long-lasting Glow-in-the-dark Material

Long-lasting Glow-in-the-dark material can absorb and store light/heat energy, then it can glow in the dark. It can be recharged and provide unlimited glowing. Also, it can be charged faster by exposure to the sunlight/UV light. The long-lasting glow powder is a pigment which is suitable for plastic injection and solvent based ink or paint. Its benefits are having a good weather resistance, applicable to both indoor and outdoor (New Prismatic Co. LTD, 2008a).

Figure 2-30 shows the colour conversion of Long-lasting Glow-in-the dark material.

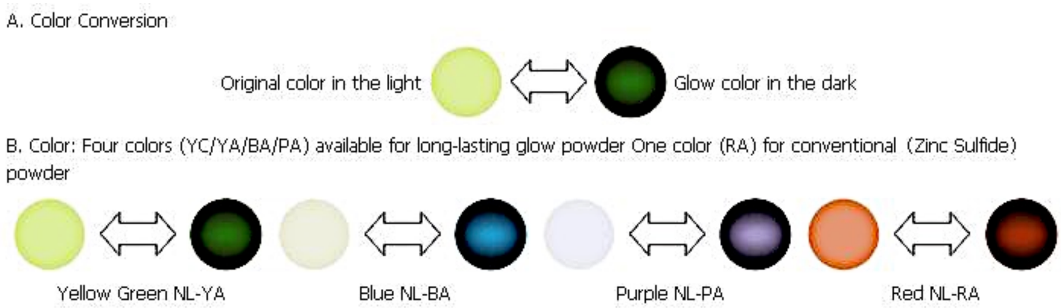


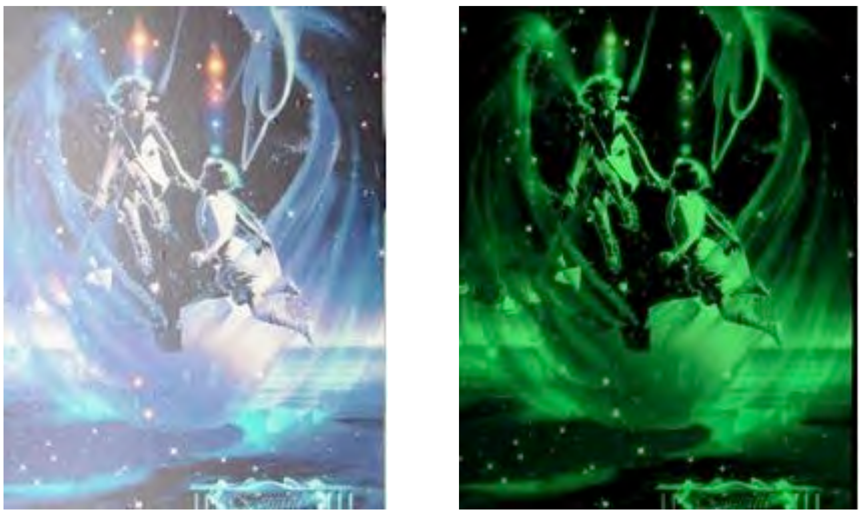
Figure 2-30: Colour Conversion of Glow-in-the-dark Material

2.5.4.2 History of Photochromic

The first photochromic lenses were made of glass and developed by scientists in the U.S. at Corning. The plastic photochromic lenses as we know them today are the process of quite a history, the first photochromic lenses that were introduced in 1966. It became popular and started taking over the market, back in the 1960s."They were made of glass and contained light-sensitive silver halide crystals that were mixed in while the glass was still in its molten state. Like today's lenses, they are activated by ultraviolet light from the sun. The lens material, which supports a layer of photochromic dyes, also affects how fast the lens darkens and fades" (Baldy, 2009). Due to the fact that photochromic dyes do not work well in common plastic lens materials, so companies have developed special, but proprietary monomers that are compatible with the dyes. "Companies are continuing to design new dyes by adding various substituents that absorb more into the visible region to get more activity behind auto windshields" (Erickson, 2009, p.54).

2.5.4.3 Applications of Photochromic and Long-lasting Glow-in-the-dark Materials

For the purposes of painting and screen printing, the Long-lasting Glow-in-the-dark materials are recommended to use neutral or weak alkaline clear resin. In order to avoid precipitates of glow powder occurred in glow paint, it is needed to use with high-viscosity resin and ant-precipitation agent to the paint and make sure stirred well before use. Also, it is recommended not to add any heavy metal compounds. For the best result, use white or light colour as a background as any colour other than white will diminish glow. For the best result, a 80-120 mesh screen is suggested to use for screen printing. Figure 2-31 shows an example of before and after finishing products by using Long-lasting Glow-in-the-dark material (New Prismatic Co. LTD, 2008a).



Light **Dark**

Figure 2-31: Before and after: Products using Long-lasting Glow-in-the-dark material.

Figure 2-32 shows the photochromic guidelines of applications for paint and screen printing ink. It is suggested that the photochromic dye cannot be injected and moulded at temperatures over 250c due to its low decomposition temperature. For the best result, aqueous based ink or paint with 5% to 60% is recommended.

Available Products / Applicability	Dye	Slurry	Microencapsulated powder	PS Powder	Masterbatch
Ink/Paint (Solvent)	△	×	○	○	×
Ink/Paint(Aqueous)	×	○	△	○	×
Plastic Injection/Extrusion	△	×	○	×	○

○Applicable · △Conditional · ×Not Applicable

Figure 2-32: Photochromic guidelines of applications for paint and screen printing ink

Figure 2-33 shows the 'before and after' finishing effect of colour-changing yarn with Photochromic material. Figure 2-34 shows the colour-changing bracelets with photochromic material (New Prismatic Co., LTD 2008b).

Before **After**

Figure 2-33: Before and after: Colour-changing yarn using Photochromic material

Before **After**

Figure 2-34: Colour-changing bracelet by using Photochromic material

2.5.4.4 Colour-changing Technology of Photochromic

The colour changing technologies of photochromic are as follows:

- Photochromics change from clear when indoors to colour when outdoors. Specifically, photochromics change colour in response to ultraviolet light, usually from the sun or a black light.
- Photochromic behaviour can be either reversible or irreversible. Technically, all photochromism is defined as reversible, but for simplicity the term irreversible photochromic is used to describe irreversible photochemical reaction that yields a visible colour change.
- Reversible photochromics transform from clear to colour by changing their chemical structure after absorbing ultraviolet light, usually from the sun. The ultraviolet light causes the photochromics to absorb colour (like a dye), and then change back to clear when the ultraviolet source is removed. They can cycle thousands of times depending upon the application. They can also change from one colour to a different colour by combination with a permanent pigment. Standard photochromic ink will change from clear to colour when activated by ultraviolet light.
- The most famous reversible photochromic application is colour-changing lenses

for glasses, as found in transitions eye-glasses. Reversible photochromic is also found in novelty applications such as T-shirts, toys, cosmetics, and industrial applications (LCR Hallcrest, 2006).

2.6 Technologies and Application of Various Sensors

“Elements that stimulate our senses, sight, touch, sound, taste and smell from our experiences of our environment” (Baurley, 2004, p.275). Products that arouse human sensorial are always acting as an important activity as both are corresponding to each other. “Intelligent material will provide a new array of sensorial qualities, which will impact both on how we experience our surroundings and how we interact with them” (Baurley, 2004, p.275).

Schwarz (2010) pointed out that a smart textile should be able to feel the changes in the environmental condition. “A sensor is defined as a device providing information mostly in the form of an electrical signal. It senses the measured object or medium and emits a signal related to the variations of the measured quantity” (Schwarz, 2010, p.107).

2.6.1 Heat Sensor

Figure 2-34 shows a heat sensor developed by Jim Gimzewski and colleagues at BM Ruschlikon for studies of surface reactions. This device is based on the silicon levers used to detect atomic-scale protuberances on surfaces in the atomic force microscope. The changes of temperature cause the

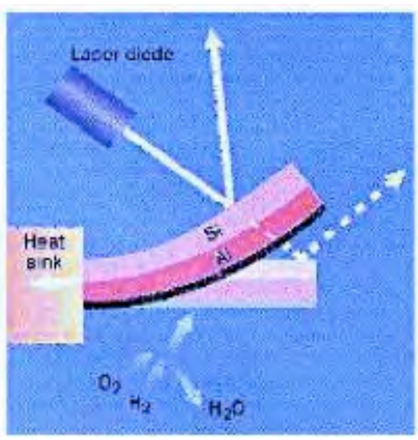


Figure 2-35: Heat Sensor

lever to bend because of the bimetallic effect. The degree of bending is proportional to the heat flux which is absorbed by the lever and also it is detected by measuring the change in direction of the reflected light beam. Radiation absorbed from the laser beam which is used as means of calibrating the degree of bending by varying the laser power. King (1994) mentioned that the lever should bend when a dose of reactive gas like oxygen, as heat will be released in the exothermic process of chemisorptions. When absorption is complete, the lever should then return to its original position.

2.6.2 Sound Sensor

The sound detection is made by the incidence of transmitted sound energy or an appropriate acoustic transducer. Lindsay (1964, p.1) stated that "acoustics was originally limited to the human experience produced by the stimulation of the human ear by sound incident from the surrounding air. Basic acoustics divided to three branches called production, transmission and detection of sound".

The acoustic emission signals are classified as burst type and continuous type. Figure 2-35 and Figure 2-36 show typical acoustic emission waveforms as detected with burst and continue type piezoelectric transducers, respectively. "The burst type emission resembles a damped sinusoid and the continuous type emission appears to consist of an overlapping sequence of individual burst. Sound waves in fluids involve local changes in the pressure, density and temperature of the media, together with motion of fluid elements" (Fahy, 1989, p.1).

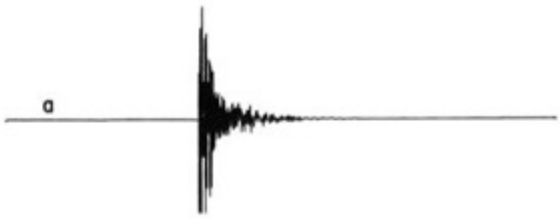


Figure 2-36: Acoustic emission waveforms detected by burst type piezoelectric transducers

Figure 2-37: Acoustic emission waveforms detected by continuous type piezoelectric transducers

Figure 2-37 shows a conventional view of acoustic emission with internal and surface sources. It shows the simplistic manner in which acoustic emission sources are usually treated (Green, 1980).

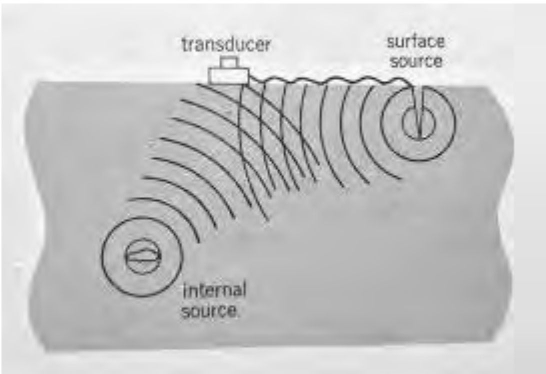


Figure 2-38: View of internal and surface sources acoustic emission

2.6.3 Pressure Sensor

A pressure sensor also known as pressure transducer, is used to measure pressure typically of gases or liquids. A pressure sensor converts pressure into an analogue electrical signal such as a voltage output or current output which can easily be measured (Alexander, et al., 1998). There are different types of pressure measurement, those are as follows: a) Absolute pressure sensor measuring the pressure relative to perfect vacuum; b) Gauge pressure sensor measuring the pressure relative to atmospheric pressure; c) Vacuum pressure sensor measuring pressure that is less than 0 PSI; d) Differential pressure sensor measuring the difference between two pressures points; e) Sealed pressure sensor measuring the pressure relative to some fixed pressures (Alexander, et al., 1998).

2.6.4 Radar

Radar technology was developed at the beginning of 20th century and the main purpose of it at the earliest time was to use for military during World War II (Rohde & Schwarz, 2012). There are wide range of applications of radar, for examples, weather forecast, airport traffic control and automotive applications such as adaptive cruise control, blind spot detection and active pedestrian safety (Rohde & Schwarz, 2012). The strength of radar is to measure the exact radial velocity of an object by using the Doppler effect and it can describe the apparent change in frequency of a signal emitted. Also, it reflects to an observer if an object is moving relative towards or away from its observer. Due to the fact that the observer is also the emitter of the signal, it transmits a wave and observes a moving object (Rohde & Schwarz, 2012).

2.7 Technologies and Process in Weaving

2.7.1 History of Hand Loom Weaving

The very first plain woven fabric was found in the areas of Fayum and Badari in the Nile Valley located in Egypt in 5,000 B.C. In the past, it is not necessary to set up a loom for processing as simple weaving could be done with fingers (Held, 1978). However, it has started to become necessary to devise a frame to hold and stretch the warp threads when pliant thread has to be woven due to the considerable length of web is required. “ The more or less elaborate frame constructed for this purpose, with the properly arranged warp mounted on it, together with the various contrivances added from time to time by the weaver’s ingenuity, has by universal consent been called a loom” (Hooper, 1979 p.18).

2.7.2 Setting up Instructions for Hand Loom Machine and Weaving Process

A basic table loom is shown in Figure 2-38 (Creager, 2006). Before starting to weave, there is a setting up process which is as follow:

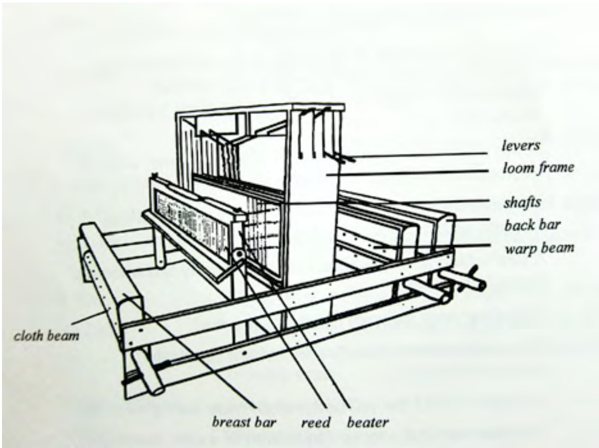


Figure 2-39: Basic table loom

1) Choice of yarn

The yarn should be strong enough to stand the strain of weaving and any textured and fibrous yarn should not be used as it will be difficult to pass through the heddle and reed to make the warp (Creager, 2006).

2) Calculating the number of threads required and length of the warp

One has to multiply the number of threads per inch by the width of cloth required. When deciding the length of warp, one should take account the inches of warp that will be unavoidably wasted at the beginning and end of cloth as well as the cloth’s contraction once it has been taken off from the loom (Creager, 2006).

3) Warping

This is an important preparation process before weaving as the success of a weaving depends on the quality of warp. So, it is essential that the warp is carefully prepared. The warping frame is shown in Figure 2-39 (Creager, 2006).

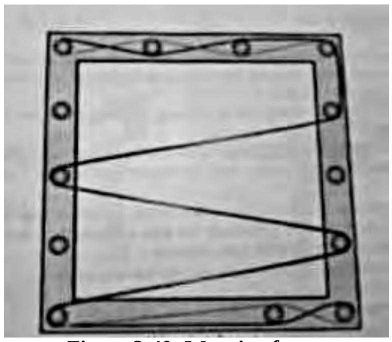


Figure 2-40: Warping frame

4) Warping and dressing a table loom

Getting the warp on the loom ready for weaving is called dressing the loom. There are four main processes involved: (a) beaming the warp means winding the warp on to the warp beam; (b) threading the warp ends through the heddles; (c) pulling the warp threads through the reed (Figure 2-40); and (d) tying on the warp and fastening the warp to the cloth beam (Creager, 2006).

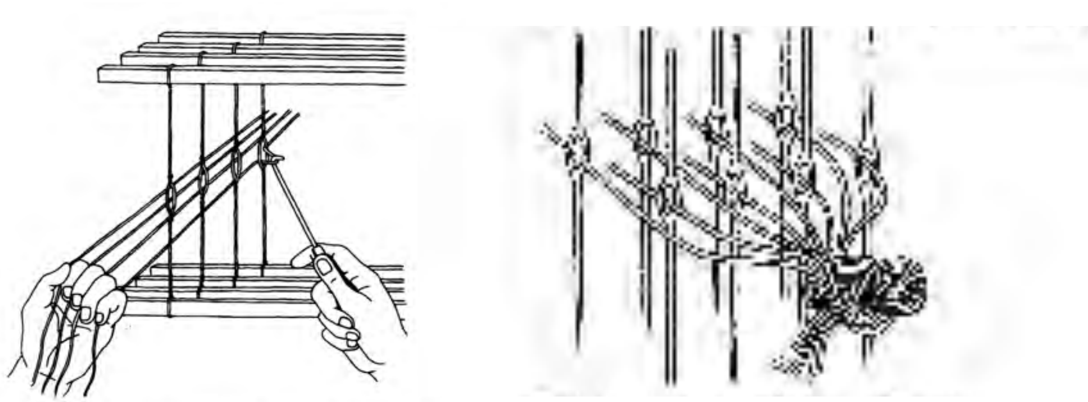


Figure 2-41: Threading the warp

5) Choice of reed

The choice of reed should be based on the yarn character, the density of the warp set, as well as the requirements of specific cloth construction. In addition, the reed spacing must be sufficiently wide to let the passage of knotted yarn without undue friction. Also, it is important to keep the friction caused by the reed to a minimum because it has to avoid putting a single end in a dent, as the reed wired take up too much space and rub against the yarn. Moreover, hairy or any yarn that tends to stick together should wherever possible be entered two ends in a dent only to avoid abrasion (Creager, 2006).

6) Tying on the warp

After all the above procedures, the next stage is trying on the front apron. Figure 2-42 shows how to tie the ready warp on the apron. It should work from the centre towards each side, tighten the knots by pulling both ends of the knot toward the reed and complete the tie. Finally, the warp should be checked and ensured that it is at an equal tension across the width (Creager, 2006).

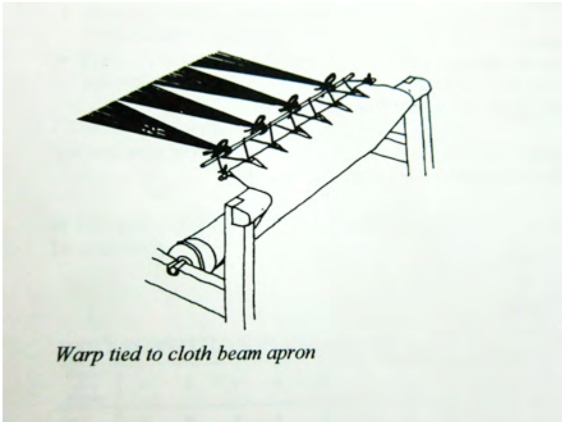


Figure 2-42: Warp tied to cloth beam apron

7) Start weaving

One has to lift each shaft in turn to check that there are no errors in threading. Then, one can start winding the weft on a shuttle. If the shuttle is of the stick type, it is suggested to wing the yarn around the edge as well as in the centre. Meanwhile, a flatter shuttle with the maximum amount of yarn should be prepared. The weaving sequences are as follows: (a) opening the first shed; (b) inserting shuttle; (c) beating up; (d) opening next shed; and (e) keep repeating the all steps to weave (Creager, 2006).

2.7.3 Advantages of Hand Loom Machine in Weaving

The advantages of Hand Loom machine in weaving are as follows:

- The loom has a shed stick and heddle which make the weaving go faster and more uniformly than on an even simpler loom where the weaver must intertwine the warp and weft with just the fingers.
- The frame loom requires less time in construction and in setting up the warp than the more complex foot-powered loom, but it requires a greater investment in time spent in the actual weaving of the fabric.
- Even though it is slower and simpler than other looms, the frame loom has certain advantages to be considered.
- Only the frame loom can be made big enough to weave large, one-piece fabrics, rugs and mats. Variations of this loom are used, to weave Persian or Oriental rugs in Afghanistan and Iran.
- Another advantage of the frame loom is that it is especially suited to weaving very coarse fibres and is useful for weaving heavy mats of straw, grasses or similar fibres. The frame loom is also very suitable for weaving pile or shag rugs, and tapestries. The knotted and tapestry weaves used for such rugs require slow painstaking finger weaving by the weaver no matter which style of loom is used, and so the foot-powered loom loses its advantage of greater speed when this kind of work is being done (Creager, 2006).

2.7.4 History of Jacquard Machine Weaving

During the Industrial Revolution, mechanical looms were introduced. In 1801, Joseph Marie Jacquard invented the first loom that could be made to weave more complicated patterns into the fabric. The loom he invented was subsequently given his name. In 1983, the first computer-based Jacquard loom was invented in Milan.

Today's the Jacquard loom can weave more than 10,000 threads at once and it is very commonly use for mass production in fashion and textiles (Murray, 2008).

2.7.5 Setting up Jacquard Machine

Computer-aided design (CAD) has been carried out over the many years and it is a programme to help enhancing the design efficiency of jacquard fabric. It is not a technology directly applied to Jacquard designs and it has been replaced only for the procedures of hand-drawn patterns and point papers. The traditional way of producing Jacquard textile involves three major steps: (a) pattern and colour design; (b) weave and structure design; and (c) craft design consisting of point paper drawing and card-cutting planning (Ng & Zhou, 2013).

Basically, the weft threads are used to adjust the colour brightness of the surface fabric. Therefore, the colour arrangement of the warp and weft is very important in the fabric design. Thus, the colour pattern effect depends on the woven structures that textile designers create during their design on CAD. "Innovation in jacquard textiles is based on the application of textile materials and their corresponding finishing techniques and/or fabric structure" (Ng & Zhou, 2013, p.32).

2.7.6 Advantages of Jacquard Machine in Weaving

A Jacquard loom located at the Hong Kong Polytechnic University is shown on Figure 2-43. It is able to transfer every detail of the original input pattern as well as weaving larger size of fabrics. The size of Hand Loom

Figure 2-43: Jacquard weaving machine

machine is smaller than the Jacquard loom machine. The traditional table loom is not able to produce the exact pattern from the original design pattern. Therefore, textiles designers can pick detailed patterns and enlarge the design and transfer to the woven fabrics.

Furthermore, according to the inventor, Joseph-Marie Jacquard (1752) stated that Jacquard loom could produce complex patterns as easily as earlier machines had produced plain cloth, and it served as the basis of the modern automatic loom. Besides the Jacquard loom also allowed for a greater variety of yarns to be used and more diversified fabrics that can be made with the aid of a loom rather than by hand. It helps eliminating the time spent stopping the Hand Loom and replacing the cards for the next section of the fabric. “Digital textile design is one of the most important research directions in advanced textile technology and science. Development of innovative textile products is of both artistic and commercial value” (Ng & Zhou, 2013, p.3).

2.7.7 Weaving with Conductive yarn by Jacquard Loom Machine


Figure 2-44: Conductive Fabrics

Conductive fabrics (Figure 2-44) are mostly made by either basic woven or knit structures. Conductive yarn is metallic, shiny and uniform. It can let designers tailor the electrical properties of the fabric to their own designs. Besides, various colour, texture, patterns and aesthetic qualities can be added to the fabric. In the ‘Involving the Machines’ (ITM) research project, fabrics are woven with conductive, resistive and non-conductive (cotton) thread. Both conductive and resistive threads should be woven with float on the back so that one can cut the weft connection on the back. Each pattern on the front side of the fabric can act as individual conductive, resistive and non-conductive surface, which can be used as sensor or circuit. By cutting the floating conductive threads on the reverse side of the fabric, it can create separated areas of conductivity and resistance (Satomi & Wilson, 2012).

2.7.8 Screen Printing of Conductive Inks

Pourdeyhimi et al. (2006) investigated the integration of non-woven textile and control of dispensing conductive inks for manufacturing textile printed circuit boards and suggested that deposited screen printed conductive silver inks with a coating of melt-blown layer showed the best result in terms of internal electrical properties, and interconnections between substrate and other components. Besides, the final electronic textile exhibited the general property of an ordinary textile such as, outlook and hand feel.

2.7.9 Machine Sewing with Conductive yarn

According to Orth's (2003, p.11) material research, most conductive yarns are generally used for industrial purposes. Flexibility in conducti ve yarn is important as it allows electric textiles to be intimate, soft, wearable, comfortable and durable. This method can easily incorporate fibres into clothing (see Figure 2-45). The general characteristics of machine sewable yarn should have high tenacity from 580 to 1,200cN, percentage

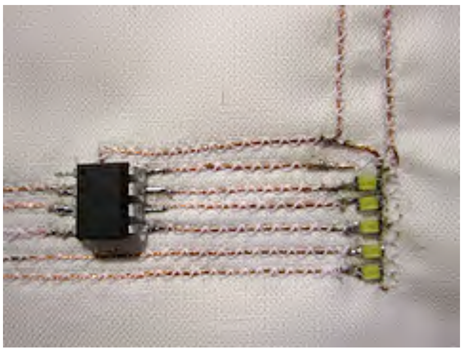


Figure 2-45: Machine sewing with conductive

of elongation at break between 12-30%, and small denier under 400 with smooth and even surface finish.

2.8 Research Gap

The latest research studies related to illuminative and colour-changing fashion, interior and accessory products; technologies and applications of illuminative materials; sensors detecting surrounding environment; and weaving textiles technologies were systematically reviewed. However, no systematic design process model has been established in order to achieve the functional and innovative aspects of colour-changing smart home textile products.

In order to achieve the proposed design creation of colouring-changing smart home textiles with full consideration of innovative and technological requirements of colour-changing materials, sensors and circuit layout design, as well as weaving structures and weaving machine, the following research gaps are required to be filled:

- The design process model of colour-changing smart home textiles has not yet been available.
- The selection of colour-changing materials for smart home has not been fully discussed in the related research studies and its corresponding prototypes have not been developed.
- The integration of various sensors that can detect changing environment for home textile products has not been achieved.
- The development of woven fabrics combined with colour-changing materials by using hand loom and jacquard machine has not been fully explored in the field

of interior design.

- The development of circuit layout designs into woven fabrics for smart home textiles has not been fully explored and discussed.
- The specific integration of sensors, materials, colours and pattern for smart home textiles has not been developed.

2.9 Conclusion

The colour-changing and illuminative smart home fashion and textiles products are discussed in this chapter. Literature of the related technologies and applications of smart fashion and textiles design such as, various illuminative and colour-changing materials, sensors, weaving techniques and processes were systemically reviewed. Finally, the research gaps are explored and identified.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

The practice-based research methodology was adopted in this research study. The research design of this study was divided in five major stages: ‘research stage’, ‘analysis stage’, ‘design of initial prototypes’, ‘evaluation stage’, and ‘detail design’. The theoretical design process model of colour-changing smart home textiles was developed and based on the concept of French’s design process model as well as the adoption of product development process and engineering approach to industrial design. The final colour changing smart home textiles prototypes were then created according to the developed design process model.

3.2 Background of Practice-based Research Methodology

In the United Kindom, the first Polytechnic was formed in London in 1880. The concept of practice-based was used for the significant expansion of such institution in 1968 and its aim was to add a service element to the mainstream of higher education. The practice-based knowledge taught was to emphasise value in practice.

In 1974, the Council for National Academic Awards in the United Kingdom changed its regulations for the higher degrees to be awarded from Polytechnics and it allowed a student to submit their artefact with written work in their PhD study (Jordan, 2004). Furthermore, Schon (1990) advised that the practitioner should emphasise clearly about the process of evaluation. The qualities of practice-based documents required to: (a) contain innovative insights into practice; (b) have value to help other practitioners to improve their performance; (c) show clear evidence of professional development and innovation in their practice-based documents and detailed description of a very high level of professional creativity, sensitivity and responsibility and; (d) articulate clearly about the relationship between the research role and the practitioner role" (Winter & Griffiths, 2000, p.32).

3.3 Practice-based Research Methodology

Research that takes the nature of practice as its central focus is called "practice based" or "practice led research". Both are carried by practitioners, such as artists, designers, curators, writers, musicians, teachers and others. Research studies are not necessary done by doctoral research programmes, it has given rise to new concepts and methods in the generation of original knowledge (Candy, 2006). Central practice element is the focus of both types of research. Practice-based research is if a creative artefact is the basis of the contribution to knowledge whereas practice-led research is if the research leads primarily to new understandings about practice.

"Practice-based research is an original investigation undertaken in order to gain new knowledge partly by means of practice and the outcomes of that practice" (Candy, 2006, p.3). Practice-based research component is similar to any definition of research. The research process will be formed when the transferability of the understandings reached. The originality and contribution to knowledge may include artefacts such as mages, music, designs, models, digital, media, performances and exhibitions through creative outcomes.

"Practice-led research is concerned with the nature of practice and leads to new knowledge that has operational significance for that practice" (Candy, 2006, p.3). It is mainly focus on the advance knowledge about practice, or to advance knowledge within practice. It may be fully described in text form without the inclusion of a creative outcome in doctoral thesis results of practice-led research. In its primary focus of the research, it is to advance knowledge about practice, or to advance knowledge within practice. It includes practice in such research; it often falls within the general area of action research as it acts as an integral part of its method.

3.4 Design Process Model in Engineering, Architecture, Product and Industrial Design

The design process model is important for designers when creating new prototypes. It is described as a problem solving activity and helps designers to find out the best solution for the design problem during the whole process. It generally involves analysis, synthesis and evaluation.

3.4.1 Takala, Keinonen and Mantere (2006) Design Process Model

It is a generic framework for product development and also concept creation consisting of three layers which are the acquisition of knowledge that must be in place to allow; the successful development of product concepts; and their evaluation. Takala, Keinonen and Mantere (2006, p.62) stated that “a successful process requires input and insight from three sides: realizing the technical possibilities, understanding the users' needs and the context of use, and having a working idea about the business models around the concepts”.

The activity layers of product concept incorporate feedback loops to reflect the iterative nature of the process and details are as followings: (a) information acquisition, (b) concept creation, and (c) concept evaluation. The design of a product concept requires sufficient knowledge of customer needs, technology forecasts and the business environment.

3.4.2 Baser (2008) Design Process Model

Baser (2008) developed an industrial engineering approach to design woven fabrics in practical lines which may help to design simple or complex structures in woven fabrics. As from the engineering point of view, certain quality criteria are important when designing a fabric which can fulfil the conditions of weavability. He suggested a practical method to incorporate in computer aided woven fabric design software and the weavability and dimensional stability criteria that could be secured without any difficulties in application.

a) Analysis approach: This is a widely used approach in industry based on a full analysis of a fabric sample. It can obtain either an exact reproduction or a modified version of the sample product.

b) Technical approach: This is usually applied in designing simple fabrics to be used for shirting, sheeting, work cloths, etc. It is also used to obtain a fabric of certain unit weight with a given weave and specified raw material. This is an approach nearer to engineering design as it includes certain tables, formulae and other useful information or standard construction data. In the industrial practice point of view, designers will produce a sample fabric based on a certain design solution. At this stage, designers usually produce a series of samples each representing a certain modification or variation of the particular design solution, then the expected fabrics can be selected out of them.

c) Aesthetic approach: This is the approach mainly applied in computer aided design of fabrics and garments and it is a process starting from surface appearance of the fabric and going through the technical work.

3.4.3 Jones (1984) Design Process Model

A basic structure defined by Jones (1984) is an early example of a systematic design methodology involving consideration of the problem and its corresponding objectives. Synthesis involves the generation of a range of solutions, and evaluation involves the critical appraisal of solutions against the objectives. The structure is namely, analysis-synthesis-evaluation.

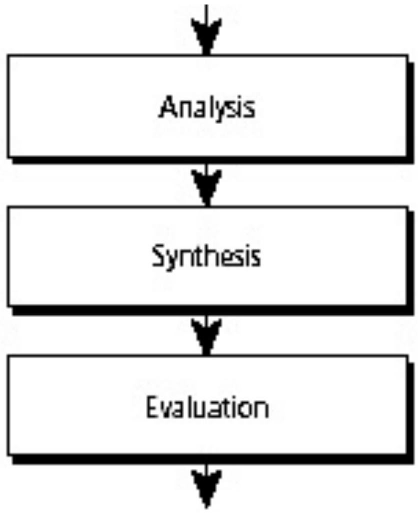


Figure 3-1: Jones (1984) Design Process Model

3.4.4 Ehrlenspiel (1995) Design Process Model

Ehrlenspiel's (1995) Design Process Model is similar to Jones Design Process Model. It is mainly based on problem solving in systems analysis illustrating the difference of design space as solutions are generated. The possible solutions are combined during evaluation and concept selection.

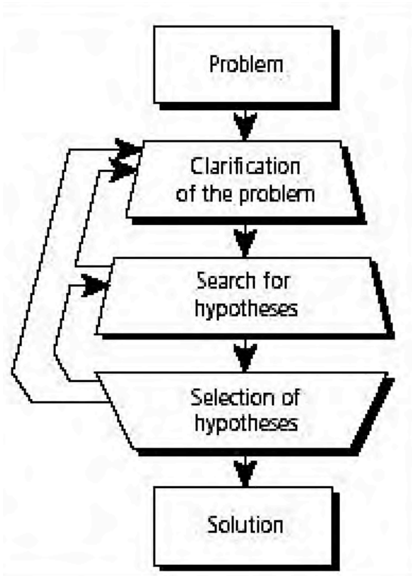


Figure 3-2: Ehrlenspiel (1995) Design Process Model

3.4.5 Archer (1984) Design Process Model

Archer (1984) identifies six types of activities in the design process model. This includes ‘programming’ to propose a course of activity at first. Second activity is ‘data collection’ to collect the required data, and to classify and store it. Next is ‘analysis’ to identify the sub-problems and to prepare specifications such as proposed programme. Then, ‘synthesis’ is to prepare, outline and create the design. Finally, they are ‘prototype design development’ and ‘communication’ to prepare manufacturing documentation. He summarises the mentioned six activities as three broad phases: analytical, creative and executive. “The bread of objective and systematic analysis may be thick or thin, but the creative act is always there in the middle” (Archer, 1984, p.25).

3.4.6 Pahl and Beitz (1996) Design Process Model

Pahl and Beitz (1996) believe that there is no ‘silver bullet’ method which can be universally applied to achieve process improvement. Instead, most methods have a well-defined and often relatively narrow focus ranging from the generation of mechanism concepts. They suggest that design-focused concept, which supports the generation of better products by the application of prescriptive models and methods to the design process.

Pahl and Beitz (1996) propose the stage-based model for mechanical design. Details are given as follows: (a) task: to collect information and elaborate the specification; (b) specification: to establish function structures, and search for suitable solution principles and combine concept variants; (c) concept: to develop preliminary layouts and form designs and then select the best preliminary layouts; refine and evaluate against technical and economic criteria; (d) preliminary layouts: to optimise and complete form designs and check for the preliminary parts list and production documents; (e) Definitive layout: to finalise details and then complete details drawings and production documents, and check all documents; (f) documentation: to check all the documents and get ready to the solution part; (g) solution: to analyse and evaluate several solution variants at each stage so as to find the solution and develop the final design.

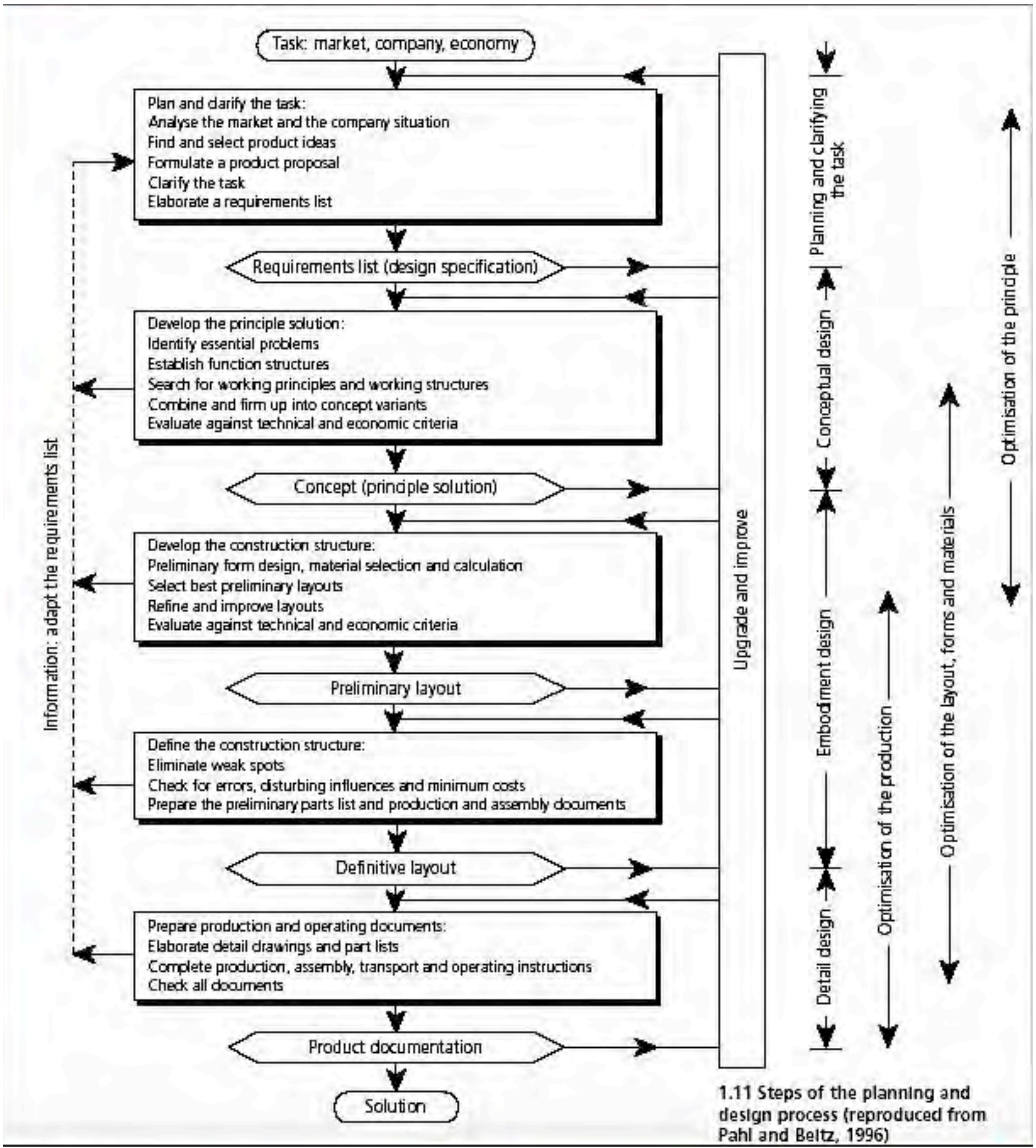


Figure 3-3: Pahl and Beitz (1996) Design Process Model

3.4.7 Lawson (1980) Design Process Model

Lawson's (1980) design process model is described as the following steps: (a) problem recognition: it includes first insight and formulation of problem, however; information constraints briefings; (b) preparation: the development of ideas and design problem have to be organised; (c) incubation: there are no conscious effort at this stage due to thinkers unknowingly repeatedly contemplating previous ideas; (d) illumination: it includes the reorganisation of previous ideas and to find a solution for further development; (e) verification: it is the final step of the design process to confirm the developed ideas.

3.4.8 Markus and Maver (1970) Design Process Model

Markus and Maver (1970) suggest that design method requires both a 'decision sequence' and a 'design process' or 'morphology'. The approaches are as follows: (a) analysis: it involves the exploration of relationships, looking for pattern in the information available, and the classification of objectives; (b) synthesis: it is to create a response to the problem; (c) appraisal: it involves the critical evaluation of suggested solutions against objectives identified in the analysis phase and then comes to the final decision step. "Markus and Maver decision sequence starts from appraisal to synthesis, which in simple terms calls for the designer to get another idea" (Lawson, 1980, p.35).

3.4.9 Darke (1979) Design Process Model

A solution-oriented model developed by Darke is described as a process of generator-conjecture-analysis: (a) think about the important aspect of problems; (b) develop a crude design on this basis; (c) examine it to discover problems. Hillier *et al*. (1972) proposed the conjecture analysis theory and suggested that a designer would pre-structure a problem in order to solve it. However, in Darke's concept, it is considered to be more a realistic descriptions of the designer's thought process than their problem-oriented counterparts. Darke (1979) argues that the designer does not start with a list of problem factors during their study; the designer would rather try to reduce the set of possible solutions to a smaller and more manageable class.

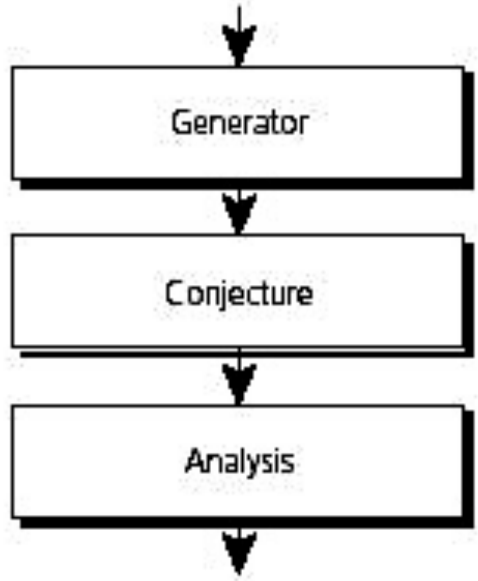


Figure 3-4 Darke (1979) Dsign Process

3.4.10 Cross (1994) Design Process Model

Cross (1994) proposes a four-stage design process model. He forms the basis of procedural design models including: (a) explore; (b) generate; (c) evaluate; and (d) communicate. He explains that the designer first explores the ill-defined problem space before generating a concept solution. The next step is to evaluate against the goals, constraints and criteria of the design brief. The final step is to communicate the design specification either for manufacture or integrate into a more complex product. Cross (1994) also includes a

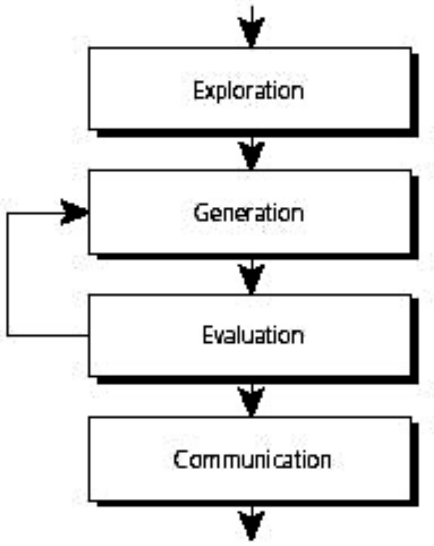


Figure 3-5: Cross (1994) Design Process Model

feedback loop between the evaluation and generation stages since generation does not always result in a satisfactory solution.

3.4.11 French (1999) Design Process Model

The French (1999) design process model begins with the 'need', and the first design step is the "analysis of the problem". His design process activities are typical of conventional engineering design and details are given as follows: (a) identifying needs; (b) analysis of problem, conceptual design, and embodiment of schemes; and (c) detailing.

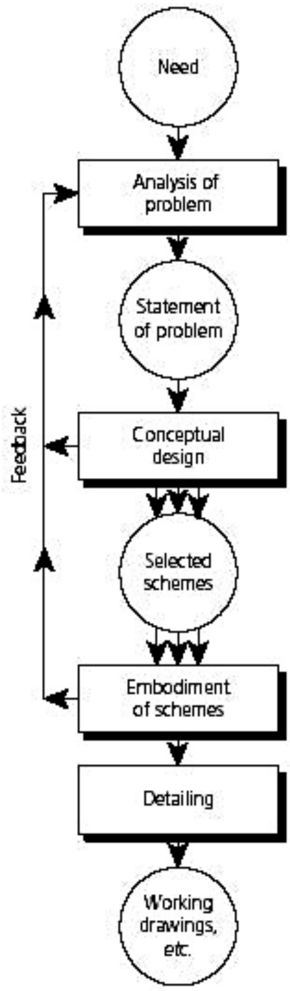


Figure 3-6: French (1999) Deign Process Model

3.5 Development of Theoretical Design Process Model for Colour-changing Smart Home Textiles

After comprehensive review of the architectural, engineering and industrial design process models, the theoretical design process model for colour-changing smart home textiles is then proposed based on the French's design process model. Its main process is as follows: (a) identifying needs; (b) analysis of problem, conceptual design, and embodiment of schemes; (c) detailing.

The first step is to study and identify the market needs. The second stage is to analyse and understand the problems. The third stage is to outline the concept of design in order to create an initial prototype. The fourth stage is to evaluate and find out the solution for specific area. The final stage is to collect all information and details of those previous experiments and to develop a detail design which creates the colour-changing smart home textile prototypes.

The Design process model for "Colour-changing Smart Home Textiles is shown in Figure 3.7.

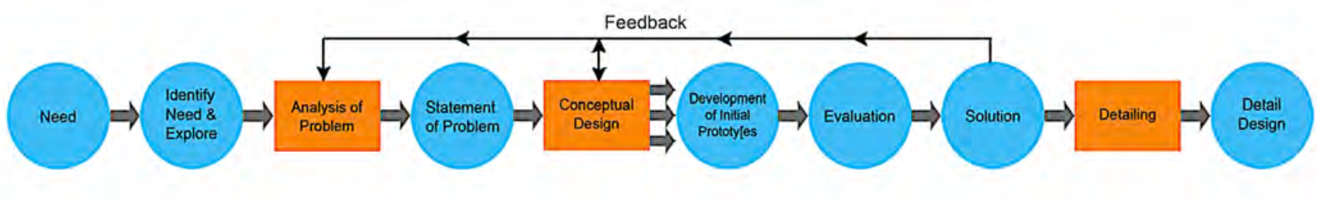


Figure 3-7: Theoretical Design Process Model for Colour-changing Smart

3.5.1 Needs

3.5.1.1 Identifying Needs and Explore (Cross, 1994; French, 1999; Takala, Keinonen & Mantere, 2006)

The information necessary to begin a design is usually based on detailed marketing studies that determine a need for a new product or service. “The design of any product or service must begin with a complete under-standing of the customer’s needs” (Chapman, Bahill & Wymore, 1992, p.12). Takala, Keinonen and Mantere (2006) suggested that one of the successful processes requires an understanding the users “needs” and the context of use. By reviewing the latest smart home textile products in the market and the related technologies and applications of smart fashion and textiles design such as, various illuminative and colour-changing materials, sensors, weaving techniques and processes, it shows a need of consumers towards interactive smart home textiles of the current market. Schwarz, et al., (2010, p.163) stated that “the further developments using smart material such as photochromics and thermochromics may offer added value because these materials have the ability to control light, temperature and colour”.

3.5.2 Analysis of Problem (French, 1985; Jones, 1984; Archer, 1984; Markus and Maver, 1970; Baser, 2008)

There are some design process models which have emphasised the need of analytical work before the solution concepts. French (1985) states that although the analysis of the problem is small, it is an important part of the overall process. Baser (2008) also mentions that the step of analysis can obtain either an exact reproduction or a modified version of the sample product. Markus and Maver (1970, p.27) suggested that “analysis involves the exploration of relationships, looking for pattern in the information available and the classification of objectives”.

3.5.2.1 Statement of Problem (Baser, 2008; French, 1985; Lawson, 1980; Maver, 1971; Jones, 1984; Enrlenspiel, 1995)

This is a stage to find out how to design and develop high-value smart home textile prototypes namely "colour-changing smart home textiles via jacquard weaving" with engineering and weaving techniques that are able to sense and response. The designer first explores the ill-defined problem space before generating a concept solution (French, 1999). "The analysis of the problem is a small but important part of the overall process" (French, 1999, p.20). Then, evaluation is needed to be taken against the goals, constraints and criteria of the design brief (Cross, 1994). And the final step is to communicate the design specification, either for manufacturing or integrating into a more complex product (Cross, 1994). A feedback loop between the evaluation and generation stage is included in this stage (Cross, 1994).

3.5.3 Conceptual Design (Archer, 1984; Paul & Beitz, 1996; French, 1999; Takala, Keinonen & Mantere 2006).

There are three main areas of design concept to be developed and details are as follows: (a) colour-changing materials; (b) various sensors; and (c) jacquard weaving fabrics. It is the phrase that makes the greatest demands on the designers, and where there is the most scope for striking improvements (French, 1999).

3.5.4 Embodiment of Scheme

3.5.4.1 Development of initial prototypes (Archer, 1984; French, 1999)

At this stage, the processes are referring to the feedbacks of the conceptual design stage. The schemes are worked up in a greater detail and the final choice will be made between those experimental samplings (French, 1999).

The colour-changing materials and specific sensors are considered to be used in developing the initial fabric prototypes. The criteria of weavability and quality of jacquard weaving samples are defined and these prototypes will be re-designed later in the final stage. The developed prototypes were as follows:

a) 9 prototypes woven by the hand loom machine with 500nm optical fibres, 100% cotton yarn, 100% polyester yarn and fire resistant polyester yarn, LEDs circuit board and sensor;

b) 3 prototypes woven by the Jacquard machine with thermal yarn, and 100% polyester yarn;

c) 18 prototypes woven by the Jacquard machine with 100% cotton yarn, 100% polyester yarn, fire resistant polyester yarn mixed with 100% cotton yarn, and screen printing with photochromic dyes;

d) 6 prototypes woven by the Jacquard machine with long lasting glow-in-the-dark yarn mixed 100% polyester yarn, long lasting glow-in-the-dark yarn mixed 100% cotton yarn, pressure sensors, and sound sensors; and

e) 6 prototypes woven by the Jacquard machine with thermal yarn mixed 100% polyester yarn.

3.5.4.2 Evaluation (Maver, 1971; Jones, 1984; Enrlenspiel, 1995; Cross, 1999)

The initial prototypes are evaluated at this stage according to the technological characteristics of the colour-changing materials, sensors and fabrications which can be integrated in to home textile. The evaluation of product concepts is one of the critical steps in the concept development process. The aim of the evaluation is to make a decision on whether to discontinue the concept, reiterate the concept or start use the concept (Takala, Keinonen & Mantere, 2006).

3.5.4.3 Solution (Baser, 2008; Jones, 1970)

After the process of evaluation, some individual solutions are created based on technological and functional requirements. It is the most important skill that a designer must develop through the design process. A designer should modify his process in response to the variable problem structure (Lawson, 1997).

Baser (2008) also stated that designers will produce a sample fabric based on a certain design solution and a series of samples each representing a certain modification or variation of the particular design solution, then the expected fabrics can be selected out of them. Also, the criteria of weavability and dimensional stability are those required conditions which make design process secured in the industrial practice design process. “In dobby and jacquard fabrics, suitable solutions may and will be searched during the process of design” (Baser, 2008, p.80).

3.5.5 Detailing

3.5.5.1 Detail Design (Pahl and Beitz, 1984; Maver, 1971)

Detail design is the final stage of the design process and it helps to develop the final prototypes. In this stage, materials will be identified. Specific weaving techniques will be applied. All drawings and other production documents will be produced (Pahl & Beitz, 1984). Finally, the high value “colour-changing smart home textile” prototypes will then be created.

Details of prototypes were fully elaborated and described as the following items:

a) Colouration
b) Colour-changing materials
c) Yarn type
d) Weaving structures
e) Graphic pattern
f) Sensors

3.7 Conclusion

In this chapter, practice-based methodology is explored and adopted in the research study. The theoretical design process model of colour-changing smart home textiles is developed after reviewing related design process models in the fields of engineering, architecture, product and industrial design. The final smart home textiles prototypes will then be created according to the developed theoretical design process model in this practice-based research study.

CHAPTER 4

DEVELOPMENT OF INITIAL PROTOTYPES

4.1 Introduction


Figure 4-1: Arctic Light

In this chapter, the initial prototypes were developed mainly by hand loom and Jacquard loom machine. They were divided into five different kinds of smart home textile prototypes namely, "smart cloth sofa", "smart curtain", "smart dining table cloth", "smart glass mat", and "smart lamp cover" for a living and dining area about 110 square feet. The integration of various sensors was conducted in a later stage.

4.2 Inspiration

The first inspiration was coming from the Arctic Lights (see figure 4-1.) as it had the colour-changing effect in the sky and the beautiful natural phenomenon was amazing. The creative hotel called the Ice Hotel located in Sweden provided some ideas for designing and developing the five initial smart home textile prototypes. Creative events for nearly 25 years have been held and hundred of artists have been selected from all over the world to design an art suite at the Ice Hotel every year only during the winter in November and December as the hotel melts and returns to Mother Nature in spring. "It's an art exhibition and hotel made of natural ice and snow from one of Europe's last wild rivers, 200 km north of the Arctic Circle, the walls, floors and ceilings of the hotel are the canvases of designers from all creative disciplines" (Ice Hotel, 1989). After reviewing the creative suites in the Ice Hotel, the five smart home textile prototypes were designed and created based on those inspiring suites.

Figure 4-2 shows an image of creative design suite in Ice Hotel and this suite was designed by three designers from Sweden, Emma Curdén, Theodor Fahlén and Gabriella Bulin. The theme was "Time Piece". "The inspiration for this suite came to us when we thought about the concept of time. It is measured in a very mechanical way and yet it is constant, in a very relative way. ICEHOTEL is a proof of this. In time there will only be water left" (Curden, et al., 2015).

Figure 4-2: Time Piece Suite at the Ice Hotel

The designers brought to mind a clock suite, they wanted to remind people about time as it was something mechanical, but time was really abstract. It was an eternity or a moment that constantly moving forward and forging changes and people did not always remember that it was there. The suite was created to let people find themselves inside a clock. It was a good example to develop and create some smart home textile prototypes for those inspiring suite in Ice Hotel.

The Smart Sofa Cloth was inserted with a sound track in order to match the design suite at the Ice Hotel. The music called "Time Travel" written and performed by Abia Ng. And this was a song written with the performer's imagination, "if there were a time machine…". Their meaning were similar to each other, both the design concept and the music were about the time. Besides, the graphic design of the Smart Sofa Cloth and Curtain were in a set developed with the same idea of water flowing after the ice melting. The inspiration came from the suite at the Ice Hotel (see figure 4-3). The

Figure 4-3: Ice Hotel Suite

design of ice pattern in the suite looked like the water is flowing.

Figure 4-4 shows another design suite at the Ice Hotel. The ice blocks looked like similar to the weaving structures. The blocks were the design idea and they were the main elements to apply and develop the graphic design of Smart Dining Table Cloth.

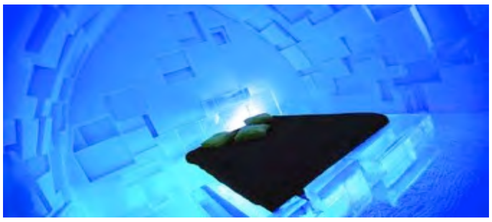


Figure 4-4: Ice Blocks Design Suite at Ice Hotel

Figure 4-5 shows a glass made of ice and figure 4-6 shows the ice glass and the ice bar at the Ice Hotel. The design idea of the Smart Glass Mat came from this ice glass and it was made of natural ice and it could serve one to three cold drinks before melting. This image was the inspiration for developing the Smart Glass Mat, as the glass was made of ice, it would be appropriate to put a thermal functional smart glass mat to show the colouring changing effect of the thermochromic yarn when reaching the related heat and humidity level.

Figure 4-5: Ice Glass at Ice hotel

Figure 4-6: Ice Bar at the Ice Hotel

Figure 4-7 shows a design suite at the Ice Hotel, the theme of the suite was called “"RENAISSANCE” designed and created by the artist, Francisco Cortés Zamudio from Sweden. “The Renaissance period was in many ways a re-birth, from the darkness of the Middle Ages to a more enlightened period, with mankind at the center; this was also reflected in the art world” (Zamudio, 2015). The artist thought that we were on the verge of a rebirth and we needed to care more about the environment and the world around us in a new way (Zamudio, 2015). The shape of the suite provided the idea of developing the Smart Lamp Cover graphic by screen printing method. The idea of the smart lamp cover was to use photochromic dye to print on the woven fabric that could be illuminated at night. As the photochromic dye absorbs energy in daytime, and this helps to save energy to the world as the lamp can still be illuminated after switching off the lamp for at least 15 minutes.

Figure 4-7: Design Suite Ice Hotel

4.3 Colouration

Colours were based on the natural colouration of the Arctic Light in the sky, as well as the ice and snow. White, pale green, yellow, aqua and red were the main colours for designing and developing the prototypes.

Figure 4-8: Colorations Mood Board

4.4 Design of Initial Smart Home Textiles Prototypes

4.4.1 Prototype 1 – Smart Sofa Cloth

Figure 4-9 shows the first design painting, "the water flowing after the ice melts". This design was scanned and saved into a jpeg format and it was further transferred to the Arahweave software on the computer for purposes of creating weaving structure and pattern editing. The sofa cloth was designed and developed by using Jacquard loom machine. It was divided into two main groups and each group was woven with different compositions of yarn types, but with the same weaving structures, plain weave, satin and twill weaving effect structures for experiments and testing afterwards. The first group was woven with Glow-in-the-dark photonics yarn with 100% polyester yarn and the second group was woven with Glow-in-the-dark photonics yarn with 100% cotton yarn.

Figure 4-9: The Design Painting for Smart Sofa Cloth, "Water Flowing after the Ice Melts"

This design aimed to make the sofa cloth illuminated both in daytime and nighttime. Also, it was inserted with medicated music for relaxing while seated on this sofa. The specific pressure sensor was also integrated within the finished woven fabric and the pre-selected sound track was automatically turned on when there was a person sitting or lying on the sofa. The target was to design a colour-changing woven sofa cloth for comfortable seats with an enjoyable lighting atmosphere with relaxing music for people with a busy life style.

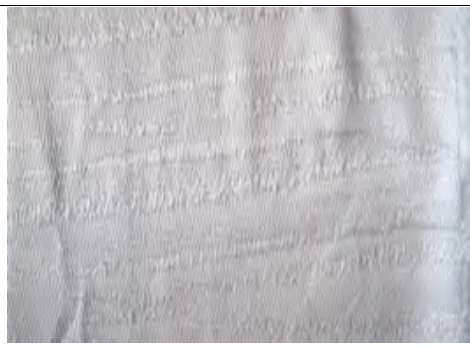
As a Jacquard loom machine was used to weave a bigger size of fabrics, that was suitable to produce the sofa cloth. Besides, a Jacquard loom machine was able to allow designers to create a more complicated weaving structure design compared to a hand loom machine. Table 4-1 shows the combinations of various materials for producing prototype 1.

Experiments with different compositions of yarn types	**Weaving structures**	**Weaving method**	**Application of sensors**
1. Glow-in-the-dark photonics yarn with 100% polyester yarn	Satin	Jacquard Loom	1. Pressure sensor 2. Sound sensor with medicated music
2. Glow-in-the-dark photonics yarn with 100% polyester yarn	Twill		
3. Glow-in-the-dark photonics yarn with 100% polyester yarn	Satin & Twill		
4. Glow-in-the-dark photonics yarn with 100% cotton yarn	Satin		
5. Glow-in-the-dark photonics yarn with 100% cotton yarn	Twill		
6. Glow-in-the-dark photonics yarn with 100% cotton yarn	Satin & Twill		

Table 4-1: Prototype 1– Smart Sofa Cloth

The initial smart sofa cloth prototypes 1 are as follows:

Figure 4-10(a): Experiment of Smart Sofa Cloth 1



(b): Experiment of Smart Sofa Cloth 2

 (c): Experiment of Smart Sofa Cloth 3	 (d): Experiment of Smart Sofa Cloth 4
 (e): Experiment of Smart Sofa Cloth 5	 (f): Experiment of Smart Sofa Cloth 6

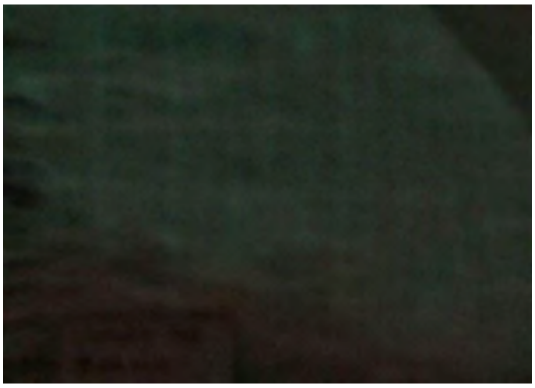


Figure 4-11: Testing the illuminative effect on 100% Cotton yarn with Twill weave

Figure 4-12: Testing the illuminative effect on 100% polyester yarn with Twill weave

Figure 4-11 shows the illuminative effect on 100% cotton yarn with twill weave and Figure 4-12 shows the illuminative effect on 100% polyester yarn with twill weave. It indicated that although both of the weaving structures were the same, the yarn type also affected the illuminative performance. The 100% polyester yarn had a better performance than the 100% cotton yarn for creating illuminative effect.

Figure 4-13: The developed pressure sensor

Figure 4-14: The amplifier consisting of two loudspeakers

Figure 4-13 shows the developed pressure sensor and Figure 4-14 shows the amplifier consisting of two loudspeakers. The amplifier was connected with the pressure sensor in order to play music when sensing a pressure signal.

4.4.2 Prototype 2 – Smart Curtain

Figure 4-15 shows the design motif, "Mirrored Effect of Water Flowing Pattern". This smart curtain was woven by Jacquard loom machine with plain weave, satin and twill structures. In order to create a durable and tightening effect of the fabric, the woven samples were woven with 100% polyester yarn with 17 degree thermochromic yarn.

Figure 4-15: Design Painting for Smart Curtain, " Mirrored effect of water flowing pattern"

None of the sensor application was needed with this prototype as the 17 degree thermochromic yarn could be functioned itself with its own characteristics. The 17 degree thermochromic yarn transformed from clear to aqua colour by changing its chemical structure when the temperature was under 17 degree Celsius. However, it could change back to clear colour when the temperature was higher than 17 degree Celsius.

This smart curtain provided a light-weight fabric handle with colour-changing effects. It was able to bring smart home living style with its technology to human life, especially for those who were fond of smart textile woven fabrics with colour-changing technology. Table 4-2 shows the combinations of various materials for producing prototype 2.

Experiments with different compositions of yarn types	Weaving structures	Weaving method	Application of sensors
1. 17 degree yarn and 100% polyester yarn	Satin	Jacquard Loom	NIL
2. 17 degree yarn and 100% polyester yarn	Twill		
3. 17 degree yarn and 100% polyester yarn	Satin & Twill		

Table 4-2: Prototype 2 – Smart Curtain

The initial smart curtain prototypes are as follows:

		
Figure 4-16(a): Experiment of Smart Curtain 1	**(b): Experiment of Smart Curtain 2**	**(c): Experiment of Smart Curtain 3**

4.4.3 Prototype 3 – Smart Dining Table Cloth

A rectangular table cloth was woven by hand loom machine by using 100% cotton yarn, 100% polyester yarn, fire resistant polyester yarn and the 500mm pre-treat optical fibre. It was divided into four main groups and each of the group was using different compositions of yarn types, but with same basic weaving structures, plain weave, basket weave and checks weave in order to evaluate the outcome afterwards. This was the only prototype that was woven with the hand loom machine because the pre-treat optical fibre was not suitable to be woven by the Jacquard loom machine and it might break the machine as well as breaking the pre-treat optical fibre. This was also the main reason why this prototype was woven with basic weaves and not with those complicated weaving structures.

The hand woven fabric was integrated with a LED light source and radar. The radar was able to detect people approaching one foot near the sensor. Once the radar detected an object within one foot; the electricity power of the LED light source was switched on and the optical fibre was then lit up. For example, when you only want to get some water from the dining table during night time, you did not have to turn on the dinning room lighting for illumination. Table 4-3 shows the combinations of various materials for producing prototype 3.

Experiment with different compositions of yarn types	**Weaving structures**	**Weaving method**	**Application of sensors**
1. 100% polyester yarn, optical fibre	Plain weave	Hand Loom	1. Radar 2. Light Source (LED)
2. 100% polyester yarn, optical fibre	Basket weave		
3. 100% polyester yarn, optical fibre	Checks weave		
4. 100% cotton yarn, optical fibre	Plain weave		
5. 100% cotton yarn, optical fibre	Basket weave		
6. 100% cotton yarn, optical fibre	Checks weave		
7. 100% polyester yarn, 100% cotton yarn, Optical Fibre	Plain weave		
8. 100% polyester yarn, 100% cotton yarn, optical fibre	Basket weave		
9. 100% polyester yarn, 100% cotton yarn, optical fibre	Checks weave		
10. Fire resistance yarn, Optical Fibre	Plain weave		
11. Fire resistance yarn, Optical Fibre	Basket weave		
12. Fire resistance yarn, Optical Fibre	Checks weave		

Table 4-3: Prototype 3 – Smart Dining Table Cloth

The initial smart dining table cloth prototypes are as follows:

Figure 4-17(a): Experiment of Smart Dining Table Cloth 1

(b): Experiment of Smart Dining Table Cloth 2

(c)" Experiment of Smart Dining Table Cloth 3

(d): Experiment of Smart Dining Table Cloth 4

(e): Experiment of Smart Dining Table Cloth 5

(f): Experiment of Smart Dining Table Cloth 6

(g): Experiment of Smart Dining Table Cloth 7

(h): Experiment of Smart Dining Table Cloth 8

(i): Experiment of Smart Dining Table Cloth 9

(j): Experiment of Smart Dining Table Cloth 10

(k): Experiment of Smart Dining Table Cloth 11

(l): Experiment of Smart Dining Table Cloth 12

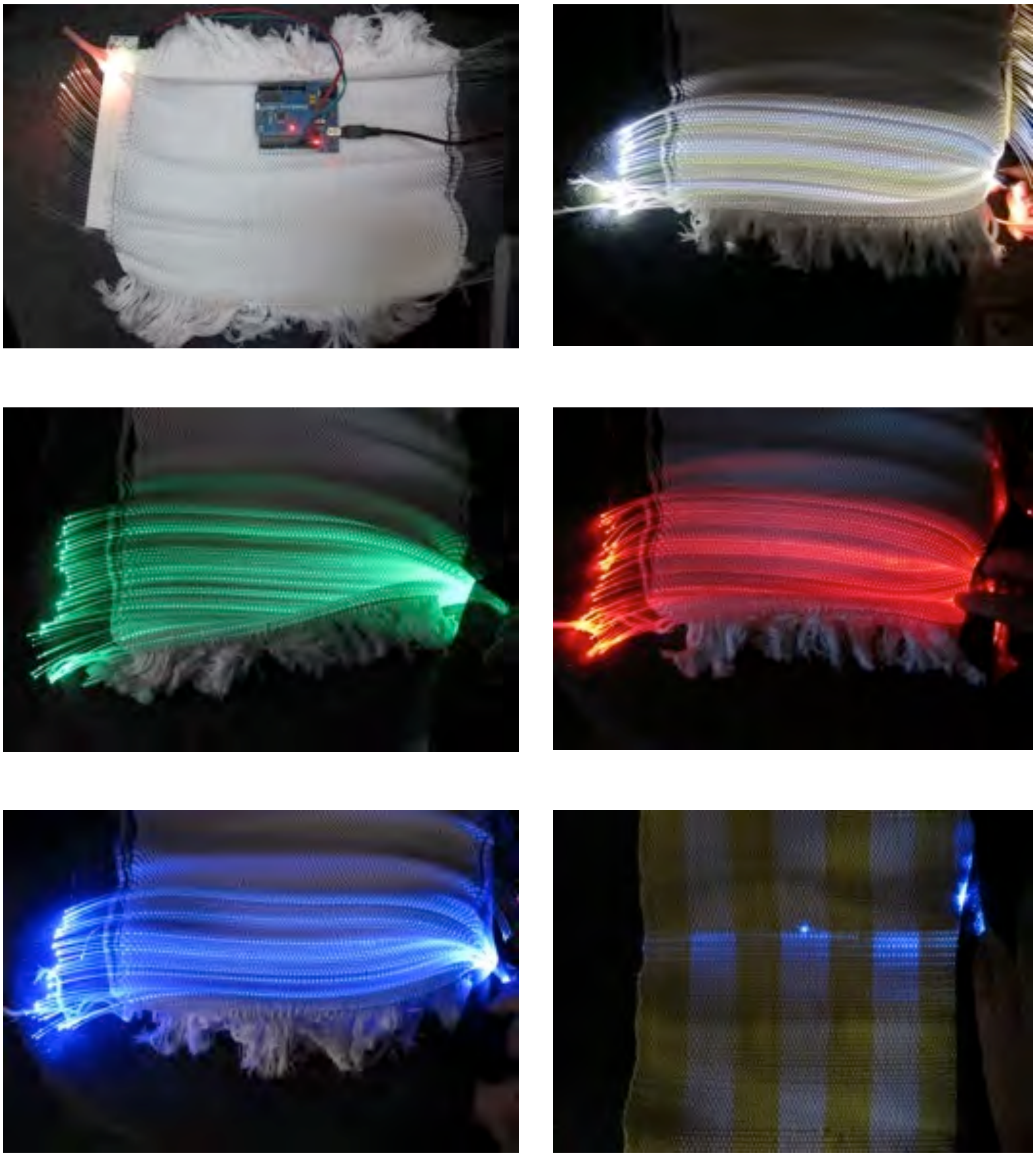


Figure 4-18: Scene of testing of the led light with the woven fabrics

Figure 4-18 shows the scene of colour-changing and illuminative effect of the optical fibres transmitting light from the LED light source. It presented the common colours, white, green, red, blue from the LED light source making the woven fabric illuminate after weaving the optical fibres into the samples. The scene on the top left shows the LED light source supplies power and light for the optical fibres. However it was not applicable to use the Jacquard loom machine for weaving the fabric because of the non-bendable properties of optical fibres. The optical fibres could break during operation due to the speed of the Jacquard loom machine. Therefore, it was suggested to weave with the hand loom machine.

Figure 4-19 shows the mobile remote control for developing the Smart Dinning Table Cloth. There was an apps written for this Smart prototype and it could be used as a remote to control the colour-changing effect of the Smart Dinning Table Cloth. At the bottom, figure 4-20 shows the step of 1 to 4 to connect to the device and also the remote control buttons shown on the mobile.

Figure 4-19: Mobile Remote Control

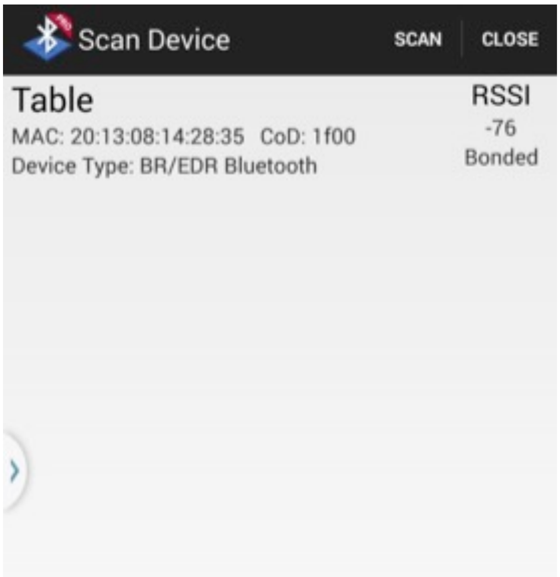


Figure 4-20(a): The remote control buttons shown on the mobile step 1

(b): The remote control buttons shown on the mobile step 2

(c): The remote control buttons shown on the mobile step 3

(d): The remote control buttons shown on the mobile step 4

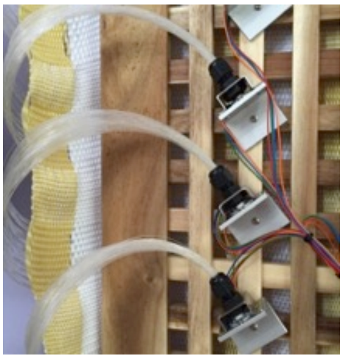


Figure 4-21: Optical Fibres Setting

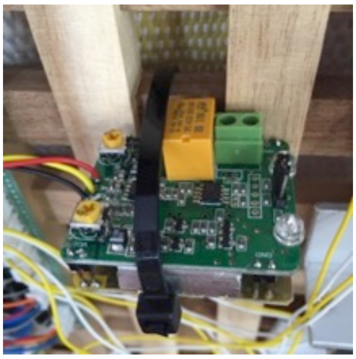


Figure 4-22: Radar of Smart Dining Table Cloth

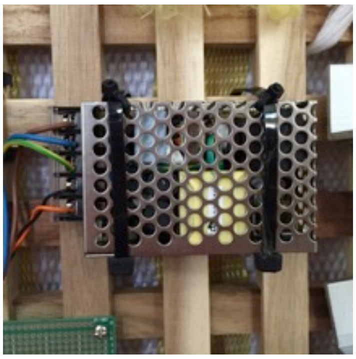


Figure 4-23: Power Supply for Smart Dining Table Cloth

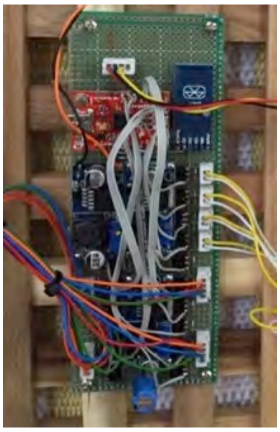


Figure 4-24: Mother Board for Smart Dining Table Cloth

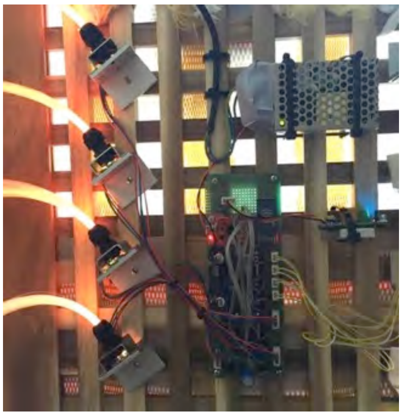


Figure 4-25: The finished sensors setting of Smart Dining Table Cloth

Figure 4-21 shows the optical fibres setting behind the woven fabric. The Smart Dining Table Cloth consisted of a power supply (see figure 4-23) providing electricity power for the LED light source. It was connected to the mother board (see figure 4-24) and the radar. Once switching on, the LED lights could transmit light source for the optical fibres and create colour-changing illuminative effect for the Smart Dining Table Cloth. Figure 4-25 shows the setting of the finished sensors embedded on the Smart Dining Table Cloth.

4.4.4 Prototype 4 – Smart Glass Mat

Glass mat was woven by Jacquard loom machine with thermal yarn and fire resistance 100% polyester yarn. It was divided into two main groups and both groups were woven with plain weave, satin and twill weave structures. For example, a glass of iced water was put on the glass mat, the glass mat was able to show a colour-changing effect because of its thermal properties. This mat did not require any electricity supply as the thermal material could provide illuminative effect itself. Table 4-4 shows the combinations of various materials for producing prototype 4.

Experiment with different compositions of yarns type	**Weaving structures**	**Weaving method**	**Application of sensors**
1. 17 degree thermal yarn, 100% polyester yarn	Plain	Jacquard Loom	NIL
2. 17 degree thermal yarn, 100% polyester yarn	Satin (pattern 105)		
3. 17 degree thermal yarn, 100% polyester yarn	Satin (Pattern 201)		
4. 17 degree thermal yarn, 100% polyester yarn	Twill (pattern 202)		
5. 17 degree thermal yarn, 100% polyester yarn	Twill (pattern 104)		
6. 17 degree thermal yarn, 100% polyester yarn	Satin & Twill		

Table 4-4: Prototype 4 – Smart Glass Mat

The initial smart glass mat prototypes are as follow:

Figure 4-26(a): Experiment of Smart Glass Mat 1

(b): Experiment of Smart Glass Mat 2

(c): Experiment of Smart Glass Mat 3

(d): Experiment of Smart Glass Mat 4

(e): Experiment of Smart Glass Mat 5

(f): Experiment of Smart Glass Mat 6

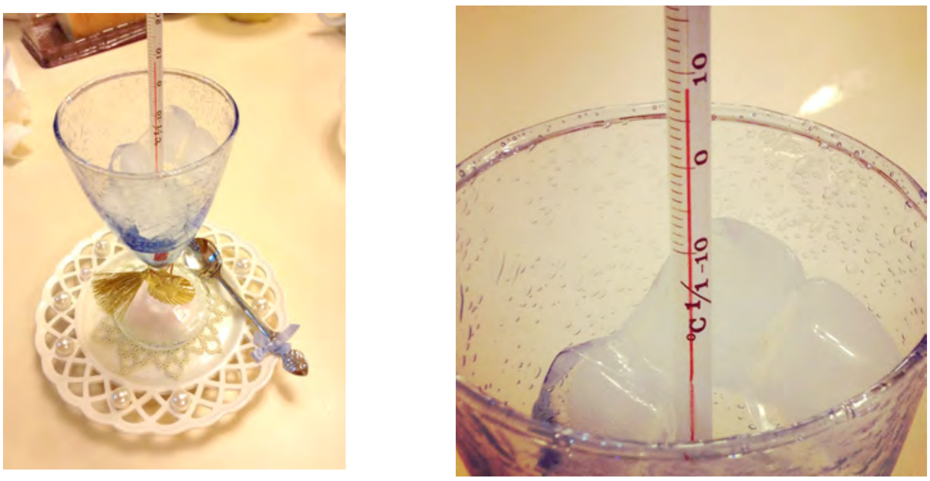


Figure 4-27: Humidity Detection of the Smart Glass Mat

4.4.5 Prototype 5 – Smart Lamp Cover

The lamp cover is woven with Jacquard Loom Machine and it is divided into six main groups. Each group is woven with different compositions of yarn types but with the same weaving structure. The compositions of yarn types include 100% polyester yarn, 100% cotton yarn, fire resistance polyester yarn with 100% cotton yarn.

Group 1 is woven with 100% cotton yarn and 3 different weaving structures to create a design graphic by applying satin weave, twill weave and satin combine twill weaving structures. Group 3 is woven with 100% polyester yarn and it is applying the same weaving structures as group 1. Group 5 is woven with fire resistance polyester yarn with cotton yarn and the weaving structures that are applied are exactly the same as group 1 and 3. Group 2 is woven with the same composition of yarn type as group 1 but without a design graphic and different weaving structures, it is woven with plain weave, satin weave and twill weave. Group 4 and 6 are similar to group 2, the differences between them are the composition of yarn type. Group 4 is woven with 100% polyester and group 6 is woven with fire resistance polyester yarn and cotton yarn.

Each group is applied with photochromic dye for screen printing onto those fabric samples afterwards. The ink absorbs energy when the light is switching on and it will show the pattern on the woven fabric. This will last for at least 3 hours after the light has been switched off. This lamp cover is designed to save the energy power at home. People can turn the lamp off at least an hour earlier before they get into bed. It creates a ready-to-bed condition for customer as well as to enjoy the specific woven fabric design, colours and patterns on the lamp. Table 4-5 to table 4-10 shows the combinations of various materials for producing prototype 5 of group 1-6.

Experiment with different compositions of yarns type	Weaving structures	Weaving method	Application of sensors/material	Others
1. 100% cotton yarn	Satin (with graphic)	Jacquard Loom	Photochromic dye	Screen Printing
2. 100% cotton yarn	Twill (with graphic)			
3. 100% cotton yarn	Satin & Twill (with graphic)			

Table 4-5: Prototype 5 - Smart Lamp Cover (group 1)

The initial smart lamp cover prototypes of group 1 are as follows:

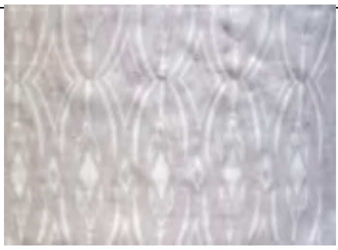


Figure 4-28(a): Experiment of Smart Lamp Cover (group 1) 1

(b): Experiment of Smart Lamp Cover (group 1) 2

(c): Experiment of Smart Lamp Cover (group 1) 3

Experiment with different compositions of yarns type	Weaving structures	Weaving method	Application of sensors/material	Others
4. 100% cotton yarn	Satin	Jacquard Loom	Photochromic dye	Screen Printing
5. 100% cotton yarn	Twill			
6. 100% cotton yarn	Plain			

Table 4-6: Prototype 5 - Smart Lamp Cover (group 2)

The initial smart lamp cover prototypes of group 2 are as follows:

Figure 4-29(a): Experiment of Smart Lamp Cover (group 2) 4

(b): Experiment of Smart Lamp Cover (group 2) 5

(c): Experiment of Smart Lamp Cover (group 2) 6

Experiment with different compositions of yarns type	Weaving structures	Weaving method	Application of sensors/material	Others
7. 100% polyester yarn	Satin (with graphic)	Jacquard Loom	Photochromic dye	Screen Printing
8. 100% polyester yarn	Twill (with graphic)			
9. 100% polyester yarn	Satin & Twill (with graphic)			

Table 4-7: Prototype 5 – Smart Lamp Cover (group 3)

The initial smart lamp cover prototypes of group 3 are as follows:

		
Figure 4-30(a): Experiment of Smart Lamp Cover (group 3) 7	**(b): Experiment of Smart Lamp Cover (group 3) 8**	**(c): Experiment of Smart Lamp Cover (group 3) 9**

Experiment with different compositions of yarn types	Weaving structures	Weaving method	Application of sensors/material	Others
10. 100% polyester yarn	Satin	Jacquard Loom	Photochromic dye	Screen Printing
11. 100% polyester yarn	Twill			
12.100% polyester yarn	Plain			

Table 4-8: Prototype 5 – Smart Lamp Cover (group 4)

Figure 4-31(a): Experiment of Smart Lamp Cover (group 4) 10

(b): Experiment of Smart Lamp Cover (group 4) 11

(c): Experiment of Smart Lamp Cover (group 4) 12

Experiment with different compositions of yarn types	**Weaving structures**	**Weaving method**	**Application of sensors/material**	**Others**
13. Fire resistance polyester yarn, 100% cotton	Satin (with graphic)	Jacquard Loom	Photochromic dye	Screen Printing
14. Fire resistance polyester yarn, 100% cotton	Twill (with graphic)			
15. Fire resistance polyester yarn, 100% cotton	Satin & Twill (with graphic)			

Table 4-9: Prototype 5 - Smart Lamp Cover (group 5)

The initial smart lamp cover prototypes of group 6 are as follows:

Figure 4-32(a): Experiment of Smart Lamp Cover (group 5) 13

(b): Experiment of Smart Lamp Cover (group 5) 14

(c): Experiment of Smart Lamp Cover (group 5) 15

Experiment with different compositions of yarn types	Weaving structures	Weaving method	Application of sensors/material	Others
16. Fire resistance polyester yarn, 100% cotton	Satin	Jacquard Loom	Photochromic dye	Screen Printing
17. Fire resistance polyester yarn, 100% cotton	Twill			
18. Fire resistance polyester yarn, 100% cotton	Plain			

Table 4-10: Prototype 5 – Smart Lamp Cover (group 6)

The initial smart lamp cover prototypes of group 6 are as follows:

		
Figure 4-33(a): Experiment of Smart Lamp Cover (group 6) 16	**(b): Experiment of Smart Lamp Cover (group 6) 17**	**(c): Experiment of Smart Lamp Cover (group 6) 18**

Figure 4-34: Light Source for Smart Lamp Cover

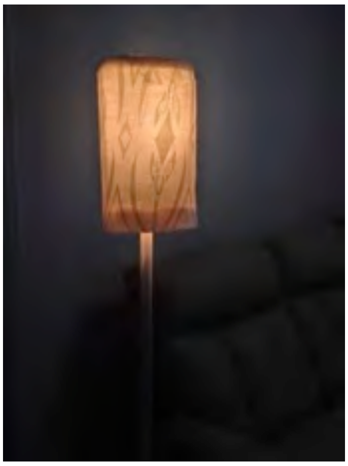


Figure 4-35: The first development of the Smart Lamp Cover

4.5 Conclusion

In this chapter, the colour-changing smart home textiles initial prototypes namely ‘Smart Sofa Cloth’, ‘Smart Curtain’, ‘Smart Dining Table Cloth’, ‘Smart Glass Mat’ and ‘Smart Lamp Cover’ inspired by the Arctic Light and the design suites at the Ice Hotel were developed. The design concept, weaving structures, sensors application, colour-changing and illuminative materials of those initial prototypes were demonstrated in this chapter. The development of initial prototypes helped to create and find the best design ideas as well as the design solutions for the final prototypes in this research study.

CHAPTER 5
EVALUATION OF INITIAL PROTOTYPES

5.1 Introduction

Before making the final initial prototypes, the confirmation of the specific illuminative materials, yarn type, weaving structures and pattern for those prototypes should be analysed in this chapter. Referring to Chapter 3, the theoretical design process model for colour-changing smart home textiles was used to assist the process of developing initial prototypes. Evaluation was one of the critical steps in the concept development process. The initial prototypes were evaluated at this stage according to the 'illuminative materials and weaving structures', and 'use of sensors' which could be integrated in to home textiles. The aim of the evaluation was to make a decision on whether to use the concept, discontinue the concept or start a new concept during the process (Takala, Keinonen & Mantere, 2006).

5.2 Assessment of Illuminative Materials and Weaving Structures

The major illuminative material for the initial prototypes in this research are LEDs, optical fibres, photonic yarn, thermal yarn and photochromic dye. To assess whether those smart illuminative materials were suitable to be applied to the woven samples for producing the final initial prototypes, corresponding tests were required to be conducted.

5.2.1 Abrasion Test Machine (D4966)

The abrasion test was to make sure the durability of woven samples as experienced in the actual use of the material. The abrasion test was used to predict the durability of each fabric related to as abrasion resistance and durability.

Figure 5-1: Abrasion Test Machine

"The relationship varies with different end uses, and different factors may be necessary in any calculation when trying to predict durability based on findings from specific abrasion tests" (ASTM D4966, 2004).

The advantage of applying Martindale abrasion test was that woven fabric samples were experiencing abrasion in all directions. The abrasion movements first modified the fabric surface and then started to affect the internal structure of fabric that may cause damaging on fabric surfaces (Manich, De Castellar & Sauri, 2001). The Martindale abrasion tests were applied on 'Smart Sofa Cloth', 'Smart Curtain', 'Smart Dinning Table Cloth', 'Smart Glass Mat' and 'Smart Lamp Cover'.

5.2.2 The Digital Lux Meter (LX1010B)

The lux test was to help testing the intensity of illumination by a lux meter and a common luxmeter consisted of the measuring device itself and a sensor. The sensor was made of selenium or silicon photocells. It was very accurate in measuring as it permited a wide range of light measurements.

Figure 5-2: Digital Lux Meter (LX1010B)

The digital lux meter LX1010B could measure up to 50,000 lux, approximately 5,000 footcandles and it was used for checking the level of luminance, luminance is a measurement of the amount of light falling on a surface. This convenient gadget was widely used in many areas such as construction, inspection, photography, etc.

The lux test was used to measure the performance of the illuminative materials like photochromic dye, glow-in-the-dark yarn and LED lights that were applied to create the initial prototypes. The lux tests were conducted on the 'Smart Sofa Cloth', 'Smart Dining Table Cloth' and 'Smart Lamp Cover'.

5.2.3 Colour Test (Colour Eye X-rite7000A)

The colour Eye 7000A test was used to test out the colour depth of the specific fabric samples. CIE L*a*b* is the most widely used data to test the colourations. The well-balanced structure of the L*a*b* colour space was based on the theory that a colour could not be both green and red at

Figure 5-3: Colour X-rite7000A machine

the same time or blue and yellow at the same time; therefore a single value could be used to describe the red/green and the yellow/blue attributes. When a colour was expressed in CIE L*a*b*, L* defined lightness; a* denoted the red/green value; and b* denoted the yellow/blue value. One of the advantages of spectral data was able to predict the effects of different light sources on an object's appearance and it was the most complete way to define a colour as it has the logical best solution for describing, specifying, or identifying colours (X-Rite Incorporated, 2013).

The various colour depths of fabric samples of 'Smart Curtain' and 'Smart Glass Mat' were tested by this machine. The reason to use this test machine for the 'Smart Curtain' was because the fabric samples were all woven by the 17 degree thermal yarn, which the test was to find out the different colour depths when the temperature was higher than 17 degree Celusis and below 17 degree Celsuis. Besides, controlling the right temperature in the chamber for those sample fabrics was also important in order to get the accurate colour depth results.

5.3 Abrasion Test on Prototype 1 – Smart Sofa Cloth

The abrasion test result with the highest average number of movement was the combination of 'Glow in the dark photonics yarn with 100% cotton yarn, woven with Satin and twill pattern' (see Table 5-1). Refer to the figures shown in the previous Chapter 4, the illuminative effect of this fabric had the brightest effect among the others. It showed the importance of picking the correct yarn as well as the correct weaving structures so as to make the fabric with better illuminative effect.

Test Method	Description of material used	Weaving structures	Weaving method	Mass of Weighs Used	Image	Average Number of Movements
Martindale Abrasion Test: D4966	1. Glow-in-the-dark photonics yarn with 100% polyester yarn	Satin	Jacquard Loom	9kpa		1000
	2. Glow-in-the-dark photonics yarn with 100% polyester yarn	Twill				2000
	3. Glow-in-the-dark photonics yarn with 100% polyester yarn	Satin & Twill				4000
Martindale Abrasion Test: D4966	4. Glow-in-the-dark photonics yarn with 100% cotton yarn	Satin	Jacquard Loom	9kpa		2000
	5. Glow-in-the-dark photonics yarn with 100% cotton yarn	Twill				4000
	6. Glow-in-the-dark photonics yarn with 100% cotton yarn	Satin & Twill				5000

Table 5-1: Smart Sofa Cloth Abrasion Test Result

5.4 Abrasion Test on Prototype 2 – Smart Curtain

The best abrasion test result of 'Smart Curtain' was the combination of '17 degree yarn and 100% polyester yarn (satin & twill)'. Its average number of movement was 3000 whereas the other two samples of the 'Smart Curtain', '17 degree yarn, 100% polyester yarn (satin)' and the '17 degree yarn, 100% polyester yarn (satin & twill)' were both having the same result with 2000 number of average movement (see Table 5-2).

Test Method	Description of material used	Weaving structures	Weaving method	Mass of Weighs Used	Image	Average Number of Movements
	1. 17 degree yarn and 100% polyester yarn	Satin				2000
Martindale Abrasion Test: D4966	2. 17 degree yarn and 100% polyester yarn	Twill	Jacquard Loom	9kpa		3000
	3. 17 degree yarn and 100% polyester yarn	Satin+Twill				2000

Table 5-2: Smart Curtain Abrasion Test Result

5.5 Abrasion Test on Prototype 3 – Smart Dining Table Cloth

Due to the fact that the 'Smart Table Cloth' was woven with the pre-treated optical fibres, it was not suitable to be tested on the abrasion test machine. According to the abrasion test D4966, the fabric was suitable for testing because testing specimen needed to be 1.5 inches (38mm) in diameter and it may break the razor blades if it is over the stated thickness.

5.6 Abrasion Test on Prototype 4 – Smart Glass Mat

Referring to abrasion test for 'Smart Glass Mat', the combination of '17 degree thermal yarn, 100% polyester yarn with twill (pattern 104)' showed the best result and it reached 4000 average number of movement comparing to the other woven samples (see Table 5-3).

Test Method	Description of material used	Weaving structures	Weaving method	Mass of Weighs Used	Image	Average Number of Movements
Martindale Abrasion Test: D4966	1. 17 degree thermal yarn, 100% polyester yarn	Plain	Jacquard Loom	9kpa		3000
	2. 17 degree thermal yarn, 100% polyester yarn	Satin (pattern 105)				2000
	3. 17 degree thermal yarn, 100% polyester yarn	Satin (Pattern 201)				100

Test Method	Description of material used	Weaving structures	Weaving method	Mass of Weighs Used	Image	Average Number of Movements
Martindale Abrasion Test: D4966	4. 17 degree thermal yarn, 100% polyester yarn	Twill (pattern 202)	Jacquard Loom	9kpa		100
	5. 17 degree thermal yarn, 100% polyester yarn	Twill (pattern 104)				4000
	6. 17 degree thermal yarn, 100% polyester yarn	Satin & Twill				50

Figure 5-3: Smart Glass Mat Abrasion Test Result

5.7 Abrasion Test on Prototype 5 – Smart Lamp Cover

The abrasion test results indicated that most of the woven fabric samples were having similar average numbers of movement, around 3,000 to 4,000. It did not occur any exaggerated breakage of yarn on the fabric surfaces. In group 1, the fabric made of '100% cotton yarn with satin and twill weaving structure' reached the highest average number of movement 4000. The fabric made of '100% cotton yarn with plain weave structure' in group 2; fabric made of '100% polyester yarn with satin and twill weaving structure' (with screen print pattern) in group 3; the fabric made of '100% polyester yarn with plain weave structure' in group 4; the fabric made of 'fire resistance polyester, 100% cotton with satin and twill weaving structure' (with screen print pattern) in group 5; and the fabric made of 'fire resistance polyester yarn, 100% cotton with plain weave structure' in group 6 had the same result as group 1. However, those woven fabric samples that reached the highest level of average movement in the abrasion test may not be chosen to develop the final prototype as the final woven fabric was required to fulfill both the durability as well as the illuminative colour-changing effect which was measured at the next stage with the lux meter (see Table 5-4 to Table 5-9).

Experiment with different composition of yarn type	**Weaving Structure**	**Weaving Method**	**Application of Material**	**Others**	**Image**	**Mass of Weights Used**	**Average Number of Movements**
1.100% cotton yarn	**Satin (with graphic)**						**3000**
2. 100% cotton yarn	**Twill (with graphic)**	**Jacquard Loom**	**Photochromic dye**	**Screen Printing**		**9kpa**	**3000**
3.100% cotton yarn	**Satin & Twill (with graphic)**						**4000**

Table 5-4: Smart Lamp Cover Abrasion Test Result (group1)

Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Application of Material	Others	Image	Mass of Weights Used	Average Number of Movements
4.100% cotton yarn	Satin	Jacquard Loom	Photochromic dye	Screen Printing		9kpa	3000
5.100% cotton yarn	Twill						3000
6.100% cotton yarn	Plain						4000

Table 5-5: Smart Lamp Cover Abrasion Test Result (group2)

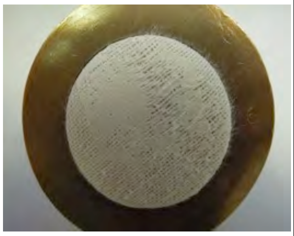
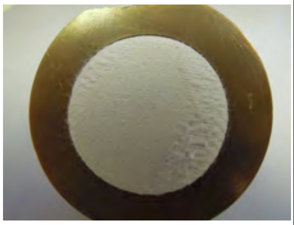
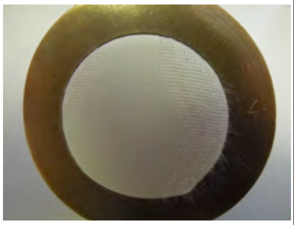
Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Application of sensors/material	Others	Image	Mass of Weights Used	Average Number of Movements
7.100% polyester yarn	Satin (with graphic)	Jacquard Loom	Photochromic dye	Screen Printing		9kpa	3000
8.100% polyester yarn	Twill (with graphic)						3000
9.100% polyester yarn	Satin & Twill (with graphic)						4000

Table 5-6: Smart Lamp Cover Abrasion Test Result (group3)

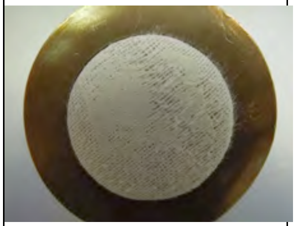
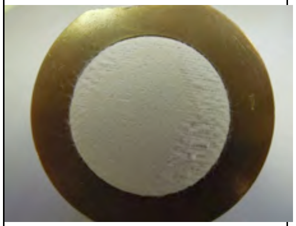
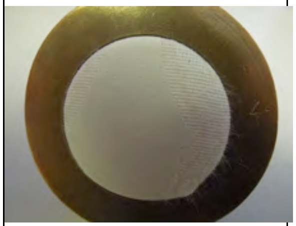
Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Application of sensors/material	Others	Image	Mass of Weights Used	Average Number of Movements
10.100% polyester yarn	Satin	Jacquard Loom	Photochromic dye	Screen Printing		9kpa	3000
11.100% polyester yarn	Twill						3000
12.100% polyester yarn	Plain						4000

Table 5-7: Smart Lamp Cover Abrasion Test Result (group4)

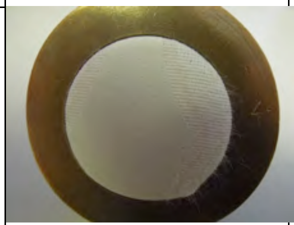
Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Application of sensors/material	Others	Image	Mass of Weights Used	Average Number of Movements
13.Fire resistance polyester yarn, 100% cotton	Satin (with graphic)						3000
14.Fire resistance polyester yarn, 100% cotton	Twill (with graphic)	Jacquard Loom	Photochromic dye	Screen Printing		9kpa	3000
15.Fire resistance polyester yarn, 100% cotton	Satin & Twill (with graphic)						4000

Table 5-8: Smart Lamp Cover Abrasion Test Results (group5)

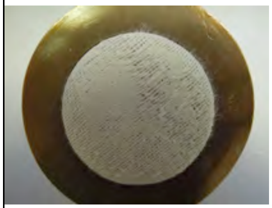
Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Application of sensors/material	Others	Image	Mass of Weights Used	Average Number of Movements
16.Fire resistance polyester yarn, 100% cotton	Satin						3000
17.Fire resistance polyester yarn, 100% cotton	Twill	Jacquard Loom	Photochromic dye	Screen Printing		9kpa	3000
18.Fire resistance polyester yarn, 100% cotton	Plain						4000

Table 5-9: Smart Lamp Cover Abrasion Test Results (group 6)

5.8 Lux Test on Prototype 1 – Smart Sofa Cloth

The best result is the fabric made of 'Glow-in-the-dark photonics yarn with 100% polyester yarn (satin & twill)', the reading of the lux meter was 2 and it had the highest reading of the lux meter compared with the others. All of the other sample fabrics were tested in the dark and had the same reading '1' of lux meter (see Table 5-10 & Table 5-11).

Experiments with different compositions of yarn types	Weaving structures	Weaving method	Application of sensors	Image	Lux Meter
1. Glow-in-the-dark photonics yarn with 100% polyester yarn	Satin	Jacquard Loom	Pressure sensor		1
2. Glow-in-the-dark photonics yarn with 100% polyester yarn	Twill				1
3. Glow-in-the-dark photonics yarn with 100% polyester yarn	Satin & Twill				2

Table 5-10: Smart Sofa Cloth Lux Test Result (group 1)

Experiments with different compositions of yarn types	Weaving structures	Weaving method	Application of sensors	Image	Lux Meter
4. Glow-in-the-dark photonics yarn with 100% cotton yarn	Satin	Jacquard Loom	Pressure sensor		1
5. Glow-in-the-dark photonics yarn with 100% cotton yarn	Twill				1
6. Glow-in-the-dark photonics yarn with 100% cotton yarn	Satin & Twill				1

Table 5-11: Smart Sofa Cloth Lux Test Result (group 2)

5.9 Lux Test on Prototype 3 – Smart Dining Table Cloth

The lux test results showed that white and blue colours have the same reading of the lux meter. ‘1’ was the lowest and ‘4’ was the highest. Both of the white and blue colours reached at the level of ‘4’ and those were also with the same composition of yarn type and weaving structures. They were both woven with ‘100% of polyester, 100% cotton and optical fibres’. Both of the samples were woven with a basket weave structure. The basket weave had a chessboard appearance and it had similar appearance as plain weave. “It is where the ‘one under – one over’ interlacing pattern is replaced by a balanced ‘m under – m over’ one, with a shift equal to m in between tow groups” (Adumitroaie & Barbero, p.4, 2011). The drapability of the basket weave was better than plain weave fabrics because it had higher abrasion movement level and performed better than plain weave fabrics. Therefore, it was suggested that both of the woven fabrics were the most suitable fabrics to develop the final ‘Smart Dining Table Cloth’ because they fulfilled the requirement of durability through the abrasion test and they both illuminated at the highest level of in the lux test due to the specific weaving structures (see Table 5-12 to Table 5-23).

Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Image	Colour of Led Light	Lux Meter
1.100% polyester yarn, optical fibre	Plain weave	Hand Loom		WHITE	2
				RED	1
				BLUE	1
				GREEN	1

Table 5-12: Smart Dining Table Cloth Lux Test Result

Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Image	Colour of Led Light	Lux Meter
2. 100% polyester yarn, optical fibre	Basket weave	Hand Loom		WHITE	3
				RED	4
				BLUE	1
				GREEN	1

Table 5-13: Smart Dining Table Cloth Lux Test Result

Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Image	Colour of Led Light	Lux Meter
3. 100% polyester yarn, optical fibre	Checks weave	Hand Loom		WHITE	2
				RED	2
				BLUE	3
				GREEN	1

Table 5-14: Smart Dining Table Cloth Lux Test Result

Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Image	Colour of Led Light	Lux Meter
4. 100% cotton yarn, optical fibre	Plain weave	Hand Loom		WHITE	2
				RED	2
				BLUE	1
				GREEN	1

Table 5-15: Smart Dining Table Cloth Lux Test Result

Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Image	Colour of Led Light	Lux Meter
5. 100% cotton yarn, optical fibre	Basket weave	Hand Loom		WHITE	4
				RED	4
				BLUE	1
				GREEN	1

Table 5-16: Smart Dining Table Cloth Lux Test Result

Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Image	Colour of Led Light	Lux Meter
6. 100% cotton yarn, optical fibre	Checks weave	Hand Loom		WHITE	1
				RED	2
				BLUE	2
				GREEN	0

Table 5-17: Smart Dining Table Cloth Lux Test Result

Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Image	Colour of Led Light	Lux Meter
7. 100%polyester yarn, 100% cotton yarn, Optical Fibre	Plain weave	Hand Loom		WHITE	2
				RED	1
				BLUE	1
				GREEN	1

Table 5-18: Smart Dining Table Cloth Lux Test Result

Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Image	Colour of Led Light	Lux Meter
8. 100% polyester yarn, 100% cotton yarn, optical fibre	Basket weave	Hand Loom		**WHITE**	**4**
				**RED**	**2**
				**BLUE**	**4**
				**GREEN**	**1**

Table 5-19: Smart Dining Table Cloth Lux Test Result

Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Image	Colour of Led Light	Lux Meter
9. 100% polyester yarn, 100% cotton yarn, optical fibre	Checks weave	Hand Loom		WHITE	1
				RED	3
				BLUE	1
				GREEN	1

Table 5-20: Smart Dining Table Cloth Lux Test Result

Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Image	Colour of Led Light	Lux Meter
10. Fire resistance yarn, Optical Fibre	Plain weave	Hand Loom		WHITE	1
				RED	1
				BLUE	0
				GREEN	0

Table 5-21: Smart Dining Table Cloth Lux Test Result

Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Image	Colour of Led Light	Lux Meter
11. Fire resistance yarn, Optical Fibre	Basket weave	Hand Loom		WHITE	1
				RED	1
				BLUE	0
				GREEN	0

Table 5-22: Smart Dining Table Cloth Lux Test Result

Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Image	Colour of Led Light	Lux Meter
12. Fire resistance yarn, Optical Fibre	Checks weave	Hand Loom		WHITE	2
				RED	3
				BLUE	1
				GREEN	2

Table 5-23: Smart Dining Table Cloth Lux Test Result

5.10 Lux Test on Prototype 5 - Smart Lamp Cover

The lux test result of the Smart Lamp Cover significantly indicated that the screen printed graphic on top of the ‘fire resistance polyester yarn, 100% cotton yarn woven fabric with the satin weaving structure in group 5’ and on top of the ‘fire resistance polyester yarn, 100% cotton yarn woven fabric with the plain eave structure in group 6’ had the best performance in the lux test. They both readings were ‘2’ of the lux meter. The other sample fabrics were mostly the same with the reading of ‘1’ of the lux meter (see Table 5-24 to Table 5-29).

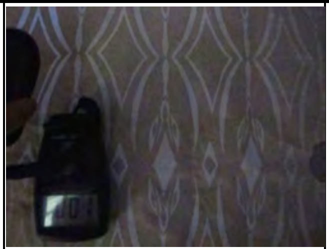
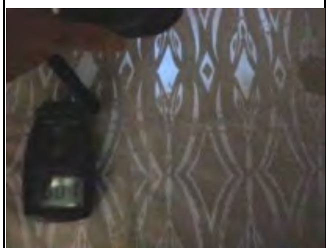
Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Application of Material	Others	Image	Lux Meter
1. 100% cotton yarn	Satin (with graphic)					1
2. 100% cotton yarn	Twill (with graphic)	Hand Loom	Photochromic dye	Screen Printing		1
3. 100% cotton yarn	Satin & Twill (with graphic)					1

Table 5-24: Smart Lamp Cover Lux Test Result (group 1)

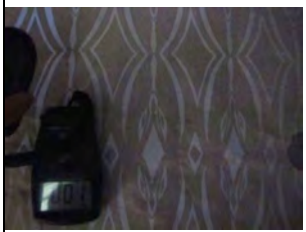
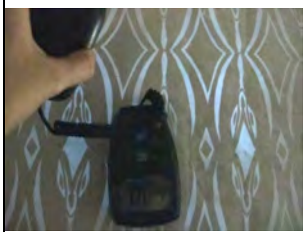
Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Application of Material	Others	Image	Lux Meter
4. 100% cotton yarn	**Satin**					**1**
5. 100% cotton yarn	**Twill**	**Jacquard Loom**	**Photochromic dye**	**Screen Printing**		**1**
6. 100% cotton yarn	**Plain**					**1**

Table 5-25: Smart Lamp Cover Lux Test (group 2)

Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Application of Material	Others	Image	Lux Meter
7. 100% polyester yarn	**Satin (with graphic)**					**1**
8. 100% polyester yarn	**Twill (with graphic)**	**Jacquard Loom**	**Photochromic dye**	**Screen Printing**		**1**
9. 100% polyester yarn	**Satin & Twill (with graphic)**					**1**

Table 5-26: Smart Lamp Cover Lux Test Result (group 3)

Experiment with different composition of yarn type	**Weaving Structure**	**Weaving Method**	**Application of Material**	**Others**	**Image**	**Lux Meter**
10. 100% polyester yarn	**Satin**					**1**
11. 100% polyester yarn	**Twill**	**Jacquard Loom**	**Photochromic dye**	**Screen Printing**		**1**
12.100% polyester yarn	**Plain**					**1**

Table 5-27: Smart Lamp Cover Lux Test Result (group 4)

Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Application of Material	Others	Image	Lux Meter
13. Fire resistance polyester yarn, 100% cotton	Satin (with graphic)					1
14. Fire resistance polyester yarn, 100% cotton	Twill (with graphic)	Jacquard Loom	Photochromic dye	Screen Printing		1
15. Fire resistance polyester yarn, 100% cotton	Satin & Twill (with graphic)					1

Table 5-28: Smart Lamp Cover Lux Test Result (group 5)

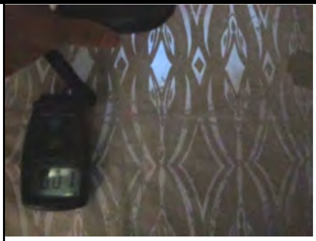
Experiment with different composition of yarn type	Weaving Structure	Weaving Method	Application of Material	Others	Image	Lux Meter
16. Fire resistance polyester yarn, 100% cotton	Satin					1
17. Fire resistance polyester yarn, 100% cotton	Twill	Jacquard Loom	Photochromic dye	Screen Printing		1
18. Fire resistance polyester yarn, 100% cotton	Plain					2

Table 5-29: Smart Lamp Cover Lux Test Result (group 6)

5.11 Colour Test on Prototype 2 – Smart Curtain

Due to the characteristics of the 17 degree thermal yarn, it was able to sense the heat and humidity, it then changed the colour from white to aqua when the temperature was below 17 degree Celsius. The test was conducted in the chamber of temperature from 17 degree Celsius to 21 degree Celsius in order to check the colour-changing differences within this range of temperatures.

Table 5-30(a), table 5-31(b) and table 5-32(c) show the lightness value and the redness value of the woven samples. The lightness value and the redness value were selected to be tested and the final Smart Curtain should be able to sense the related temperature and humidity in order to change colour to red.

Table 5-33 shows that when the woven fabrics put into the chamber with 17 degree celsius, it had the highest a* value of redness. Table 5-30 (a) shows the highest a* value on the '100% polyester woven fabric with satin weave', Table 5-31(b) shows that the '100% polyester with satin and twill weave' had the highest a* value of redness. Finally, Table 5-32 (c) shows the highest a* value on the '100% polyester woven fabric with twill weave'.

Prototype: Smart Curtain	Weaving structures	Yarn Type	Temperature (Degree Celsius)	Colour Result of Lightness Value L*	Colour Measurement of the Redness value a*
1	Satin weave	100% polyester	17	0.773	-0.166
2	Satin Weave	100% polyester	18	0.507	-0.112
3	Satin weave	100% polyester	19	0.159	0.164
4	Satin weave	100% polyester	20	0.046	-0.091

Table 5-30: Smart Curtain Colour Test Result (a)

Prototype: Smart Curtain	Weaving structures	Yarn Type	Temperature (Degree Celsius)	Colour Result of Lightness Value L*	Colour Measurement of the Redness value a*
6	Satin & Twill weave	100% polyester	17	-0.685	0.333
7	Satin Weave	100% polyester	18	-0.8015	0.224
8	Satin weave	100% polyester	19	-0.173	0.173
9	Satin weave	100% polyester	20	-7.170	0.363
10	Satin weave	100% polyester	21	-7.232	0.242

Table 5-31: Smart Curtain Colour Test Result (b)

Prototype: Smart Curtain	Weaving structures	Yarn Type	Temperature (Degree Celsius)	Colour Result of Lightness Value L*	Colour Measurement of the Redness value a*
11	Twill weave	100% polyester	17	-0.531	-0.252
12	Twill weave	100% polyester	18	-1.081	-0.202
13	Twill weave	100% polyester	19	0.131	-0.081
14	Twill weave	100% polyester	20	-0.191	-0.203
15	Twill weave	100% polyester	21	-0.095	-0.170

Table 5-32: Smart Curtain Colour Test Result (c)

5.12 Colour Test on Prototype 4 – Smart Glass Mat

Table 5-33 shows the colour test result of the Smart Glass Mat. All of the woven samples were put into the chamber and set at -1 degree Celsius and 80% of humidity as water commonly transformed to ice below 0 degree Celsius. And because of the heat and humidity detection of the yarn, it changed colour from white to red when a glass of iced water was put on the fabric, the fabric then showed a colour-changing effect because of its thermal properties. Table 5-33 shows the '100% polyester yarn with satin weaving structure' had the highest a* value and it suggested that the red colour on this woven fabric showed up the most comparing with the other samples.

Prototype: Smart Glass Mat	Weaving structures	Yarn Type	Temperature (Degree celsius)& humidity (%)	Colour Result of Lightness Value L*	Colour Measurement of the Redness value a*
1	Plain weave	100% polyester	17degree Celsius, 80% humidity	-6.212	1.835
2	Satin Weave	100% polyester	17degree Celsius, 80% humidity	-3.189	2.963
3	Twill weave	100% polyester	17degree Celsius, 80% humidity	-3.452	3.763
4	Satin & Twill Weave	100% polyester	17degree Celsius, 80% humidity	-2.897	3.993
5	Twill weave (with pattern)	100% polyester	17degree Celsius, 80% humidity	-4.476	3.202

Table 5-33: Smart Glass Mat Colour Test Result

5.13 Use of Sensors

Pressure sensor and radar detection sensor were selected and embedded into the initial prototypes. Their actual applications for colour-changing smart home textiles were described in Chapter 4.

5.13.1 Pressure Sensor

Pressure sensor was embedded in Prototype 1, 'Smart Sofa Cloth'. When pressure was applied, the change of pressure was detected. Once the target pressure was detected, a positive signal was developed and passed to the power supply circuit to switch on the amplifier to play the sound track through the two pre-installed speakers.

5.13.2 Radar Detection Sensor

The radar was used in Prototype 3, ‘Smart Dining Table Cloth’. Once the radar received a signal, for example when people walked near it within the distance of one foot, it transmitted information from it such as the time taken for it to be received, the strength of the returned signal, or the change in frequency of the signal. This information was then translated to reveal data making the LED lights to illuminate.

5.14 Conclusion

In this chapter, the initial prototypes were evaluated according to the major design elements of colour-changing smart home textiles namely, weaving structures, yarn types, illuminative material and use of relevant sensors. Individual solutions were created based on technological and functional requirements after the process of evaluation (Baser, 2008; Jones, 1970). The criteria of weavability and dimensional stability were those required conditions that make design process secured in the industrial practice design process, especially during the process of dobby and Jacquard weaving, suitable solutions should be searched during the process of design (Baser, 2008). It was a imperative design working process for a designer to develop their designs and it was suggested an evaluation part could assist designers to solve and response to such problem areas during the process (Lawson, 1997).

CHAPTER 6
CREATION OF COLOURING CHANGING SMART HOME TEXTILES

6.1 Introduction

In this chapter, the development of smart prototypes was fully discussed. The functional and innovative 'colour-changing smart home textile prototypes' was achieved according to the full consideration of innovative and technological requirements of colour-changing materials, weaving structures, colouration, graphic pattern, sensors, and application of jacquard loom machine. The previous experiments and evaluations are important factors to consider when developing a detail design for creating the colour-changing smart home textile products.

6.2 Detail Design

Detail design was the final stage of the design process and a detail design of each prototype was fully elaborated after assessing different criteria for creating the final smart home textile prototypes in this research study. A detail design with specifications for each prototype included the followings: a) colouration b) colour-changing materials; c) yarn type; d) weaving structures; e) graphic pattern; and f) use of sensor.

6.2.1 Detail design with specifications of Prototypes 1 – Smart Sofa Cloth

6.2.1.1 Colouration

The colour of the 'Smart Sofa Cloth' was inspired by the pale green colour of Arctic light and it was able to illuminate both in daytime and nighttime. The pale green colour showed up and illuminated very well when the Smart Sofa Cloth absorbed the light and it looked similar to the colour of Arctic light in the sky. The Arctic light showed better when the sky was dark. Both concepts were similar as the 'Smart Sofa Cloth' appeared at nighttime and showed up the best in the dark.

6.2.1.2 Colour-changing Materials

Glow-in-the-dark photonic yarn was the effective colour-changing material used to create Prototype 1, 'Smart Sofa Cloth'. This colour-changing material changed colour when exposed to the light and was able to absorb and store light/heat energy, then was able to glow in the dark. It could be recharged and glowed. This fabric became intensely coloured after 15 seconds in direct sunshine or light and returned to clear after about 5 minutes indoors. Its characteristic helped to produce this ‘Smart Sofa Cloth’ into a relaxation product to the interior market as well as to let the consumer enjoy the colour-changing effect of the sofa cloth.

6.2.1.3 Yarn Type

The yarn type was 100% cotton yarn and Glow-in-the-dark photonic yarn as the mixture of the yarn fulfilled both the abrasion test and lux test resulting in the highest average number of movement in the abrasion test and highest reading of lux meter in the lux test. This ‘Smart Sofa Cloth’ was woven with both of the yarn in order to create the illuminative effect as well as the best durability performance with the choice of 100% cotton yarn.

6.2.1.4 Weaving Structures

Satin and twill were the main weaving structures as they passed the abrasion test and provided the best performance for the fabric and also these structures helped to show the best design on the weaving software (see figure 6-2). “The main characteristic of the twill weave is its improved drapability as compared to plain weave, being at the same time prone to snagging when the harness is large and/or the diagonal ribs are thin” (Adumitroaie & Barbero, 2011, p.4).

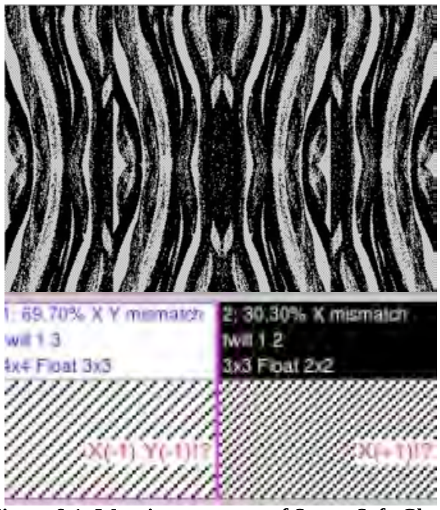


Figure 6-1: Weaving structure of Smart Sofa Cloth

Besides, twill weaves were often used for producing durable upholstery as soils and stains are less noticeable on the twill weaves (Joseph, 2011).

6.2.1.5 Graphic Pattern

Figure 6-3 shows the graphic pattern of the 'Smart Sofa Cloth' and the inspiration has come from the movements of water flowing. This graphic pattern combined with the colours as well as the music, brings a relaxation mood for consumer while sitting on the Smart Sofa Cloth.

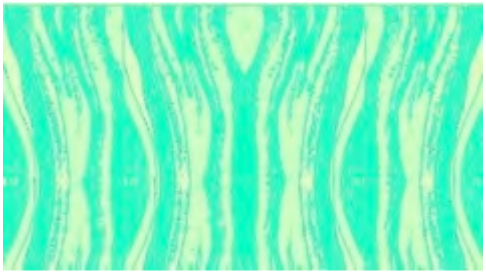


Figure 6-2: Graphic Pattern of Smart Sofa Cloth

6.2.1.6 Sensor

The specific pressure sensor was integrated with the woven fabric and the pre-selected music was able to automatically turn on when there was a person sitting on it. When the pressure sensor sensed a pressure greater than 30lbs, it then sent a specific signal to the amplifier which was then activated to start playing the music. The aim was to design a colour-changing woven sofa cloth for comfortable seats with an enjoyable lighting atmosphere and relaxing music for people who had a busy life style.

6.2.1.7 Presentation of Smart Sofa Cloth

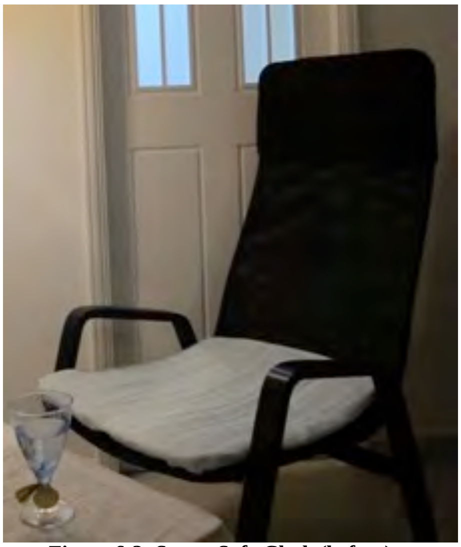


Figure 6-3: Smart Sofa Cloth (before)

Figure 6-4: Smart Sofa Cloth (after)

6.2.2 Detail design with specifications of Prototypes 2 – Smart Curtain

6.2.2.1 Colouration

White and pale green were the main colours for Prototypes 2, ‘Smart Curtain’. It was keeping the similar colour tone with the ‘Smart Sofa Cloth’ which was also inspired by the Arctic Light in order to create a whole set of home textile products.

6.2.2.2 Colour-changing materials

The 17 degree thermochromic yarn was the main colour-changing material that created colour-changing effect for the curtain as the 17 degree thermochromic yarn transformed from clear to aqua colour by changing its chemical structure when the temperature was under 17 degree Celsius.

6.2.2.3 Yarn Type

The yarn type used to weave the ‘Smart Curtain’ was 100% polyester and 17 degree thermochromic yarn. This combination of yarn type could produce a durable and tightening effect of the fabric, it created a light weight textured handle and it was able to have the colour-changing effect as the 17 degree thermochromic yarn could be functioned itself with its own characteristics.

Figure 6-5: The weaving structure of the Smart Curtain

6.2.2.4 Weaving Structures

Twill was the best weaving structure to produce the ‘Smart Curtain’ because it was the only weaving structure to show the whole graphic design pattern on the Arahweave software comparing with the other weaving structures.

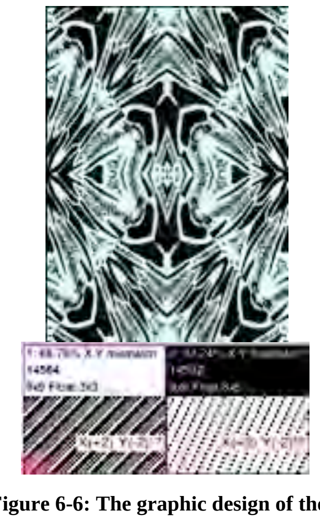


Figure 6-6: The graphic design of the Smart Curtain

6.2.2.5 Graphic Pattern

The graphic pattern was also based on the water flowing pattern and the design inspiration comes from the various solid and liquid forms of ice. Again, it was very much matching with the water flowing graphic pattern used in 'Smart Sofa Cloth'.

6.2.2.6 Presentation of Smart Curtain

Figure 6-7: Smart Curtain (before)

Figure 6-8: Smart Curtain (after)

6.2.3 Detail Design with Specifications of Prototype 3 – Smart Dining Table Cloth

6.2.3.1 Colouration

White and yellow were the main colour for the 'Smart Dining Table Cloth' when it was switched off. However, when it was turned on, it changed to multi-colours as it was connected with the LED lights with colours in white, blue, green and red. This was the prototype using different colours to present the design idea. Consumer could pick any colour they like by using the remote.

6.2.3.2 Colour-changing Materials

The colour-changing materials are LED lights and optical fibres. The pre-treated optical fibres were woven into the fabric by hand loom machine. The optical fibres were able to emit visible light when LED lights were passing through the optical fibres.

6.2.3.3 Yarn Type

The yarn type was a combination of 100% cotton, 100% polyester, fire resistant yarn and optical fibre. These yarn combined with the basket weave structure produced the best durability of woven fabric. The mixture of 100% cotton and 100% polyester yarn produced the best durable fabric and the fire resistant yarn helped to prevent high temperature from the LED lights and it helped to extend the period of time while retaining the properties of abrasion and fire retardancy.

6.2.3.4 Weaving Structure

Basket weave was the main structure of the 'Smart Dining Table Cloth'. The advantage of basket weave for producing the Smart Table Cloth was that this weaving structure helped to bring the highest level of illuminative effect from the optical fibres. Hence, the basket weave had provided the best performance of durability.

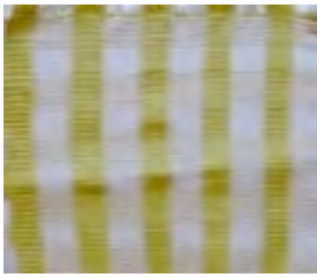


Figure 6-9: The weaving structure of the Smart Dining Table Cloth

6.2.3.5 Graphic Pattern

There was no specific graphic design on this 'Smart Dining Table Cloth' because this was the only prototype woven by hand loom machine as the optical fibre could not be bended due to its characteristic. Thus, it was not suitable to use the Jacquard loom machine to produce the fabric. The basket weave was applied in order to show the muti-colouration of the dining table cloth illuminated by the LED lights.

6.2.3.6 Sensor

A radar detection sensor was embedded into the 'Smart Table Cloth'. When the radar sensed an object waving or moving in the distance within 1 foot, it sent a signal to the main circuit board to activate the LED lights to illuminate the optical fibres as well as the table cloth. Apart from switching on the radar, the radar could be set into turned off mode with the remote. Consumer could switch on the LED lights by pressing any mode control shown on the remote.

6.2.3.7 Presentation of Smart Dining Table Cloth

Figure 6-10: Smart Dining Table Cloth (before)

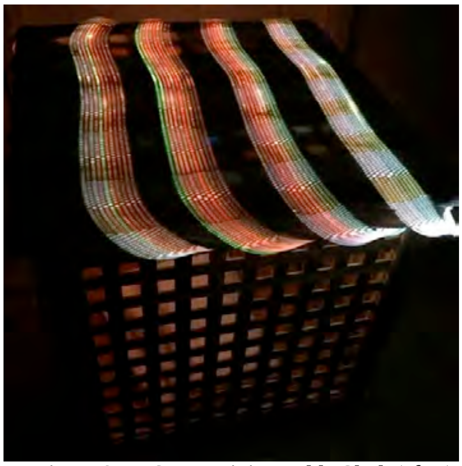


Figure 6-11: Smart Dining Table Cloth (after)

6.2.4 Detail Design with Specifications of Prototype 4 – Smart Glass Mat

6.2.4.1 Colouration

White was the main colour of the ‘Smart Glass Mat’. Some of the patterns changed from white to red colour when it sensed the relative humidity greater than 80%. It will change back to the original colour, white, after the object has been removed from the glass mat.

6.2.4.2 Colour-changing Materials

The colour-changing material was the 17 degree thermal yarn. This is the material which was able to show up the colouring changing effect when it reached the related heat and humidity level due to its thermal function. The colour-changing effect was closely related with the weaving structure and yarn type, both were the main elements that helped to stand out and show the best colour-changing effect on the glass mat.

6.2.4.3 Yarn Type

The yarn type was 100% polyester and 17 degree thermal yarn. 100% polyester yarn produced a durable woven fabric surface when it combined with the 17 degree thermal yarn referring to the result of abrasion test. Both the abrasion test and colour test results showed the important relationship between the yarn type and weaving structure. It is because this composition of yarn type worked out the best with the twill (pattern 104) weaving structure to produce a durable glass mat with the outstanding colour-changing effect.

6.2.4.4 Weaving Structure

Twill (pattern 104) was the only weaving structure to show the graphic design as well as making the 'Smart Glass Mat' turn to the red colour when a cold drinks was detected.

Figure 6-12: The weaving structure of the Smart Glass Mat

6.2.4.5 Graphic Pattern

The graphic pattern was based on the forms of sea wave and it was used to echo the 'Smart Sofa Cloth' pattern design in order to create a total look of home textiles for interior design.

6.2.4.6 Presentation of Smart Glass Mat

Figur6-13: Smart Glass Mat (before)

Figur6-14: Smart Glass Mat (after)

6.2.5 Detail Design with Specifications of Prototype 5 – Smart Lamp Cover

6.2.5.1 Colouration

White and Blue were the main colours of the 'Smart Lamp Cover'. The lamp cover changed from white colour to blue colour in the dark after absorbing the sunshine or daylight. When the light was switching on, the photochromic dye on the lamp cover absorbed light/heat energy and it then illuminated and showed the printed pattern on the woven fabric. The lamp cover became intensely coloured after 15 seconds in direct sunshine or light and this effect lasted for at least 3 hours after the light was switched off.

6.2.5.2 Colour-changing Materials

The woven fabric was applied with photochromic dye by using screen printing method. It was designed to save the energy power at home and create a ready-to-bed condition to let people turn it off before going to bed.

6.2.5.3 Yarn Type

The yarn type was fire resistance yarn and 100% cotton yarn. The composition of yarn type produced the best surface of woven fabric for screen printing. Also, due to the long period of usage of the light bulb may cause high temperature, fire resistance yarn produced a fire retardant woven fabric helped to prevent burning of the fabric

6.2.5.4 Weaving Structure

The weaving structure for developing the lamp cover is satin. The weaving structure was worked out the best with the fire resistance yarn and 100% cotton that produced a good surface of woven fabric for screen printing. The photochromic dye that was printed on top of the satin weaving structure provided the best quality of the woven fabric and it showed the best illuminative effect.

Figure 6-15: The weaving structure of the Smart Lamp Cover

6.2.5.5 Graphic Pattern

The graphic pattern for 'Smart Lamp Cover's was inspired by one of the Ice Hotel design suites located in Sweden. It was a repeated pattern that was designed and created on the Arahweave software.

Figure 6-16: The graphic pattern of the Smart Lamp Cover

6.2.5.6 Presentation of Smart Lamp Cover

Figure 6-17: Smart Lamp Cover (before)

Figure 6-18: Smart Lamp Cover (after)

6.4 Conclusion

In this chapter, the detail design with specification of the "Colour-changing Smart Home Textile" including the selection of colouration, colour-changing materials, yarn type, weaving structures, graphic pattern and use of sensor are fully discussed and applied for developing the final prototypes in this research study. These interior based smart home textile prototypes, namely 'Smart Sofa Cloth', 'Smart Curtain', 'Smart Dining Table Cloth', 'Smart Glass Mat' and 'Smart Lamp Cover' were developed by innovative Jacquard weaving method that were able to react with the changing environment factors such as pressure, humidity, heat and presence of an object in order to present and fit into the current interior and smart home textiles market.

CHAPTER 7
CONCLUSION

7.1 Introduction

The purpose of this study is to combine the creativity of textile design, applications of innovative Jacquard weaving technology as well as engineering techniques to develop high value smart home textiles prototypes namely, ‘Smart Sofa Cloth’, ‘Smart Curtain’, ‘Smart Dining Table Cloth’, ‘Smart Glass Mat’ and ‘Smart Lamp Cover’, which are able to sense and react to the changing environment by means of visual and audio communications. The research is undertaken with the objectives of: a) studying the up-to-date design products of smart home textiles; b) investigating the technologies and applications of various colour-changing materials such as, photochromic that could be integrated into smart home textiles; c) investigating how colour-changing materials can be integrated with the jacquard weaving technology for developing smart home textiles; d) developing the theoretical design process model of colour-changing smart home textiles; e) creating and assessing various colour-changing smart home textiles prototypes developed by innovative jacquard weaving; g) finalising a detail design specifications for colour changing smart home textiles prototypes; and h) creating high value colour-changing smart home textiles prototypes including ‘smart sofa cloth, curtain, dining table cloth, glass mat and lamp cover’ that can be presented and fit into the current interior and home textiles market.

7.2 Conclusion about Research Issues

This research study presents the development of a specific theoretical design process model of colour-changing smart home textiles and its practical application for creating the final smart home textiles prototypes with a full consideration of ‘innovative Jacquard weaving technology’, ‘woven fabric design’, ‘various colour-changing smart materials’, and ‘specific sensors’ such as, pressure sensor and radar detection sensor, that can fit into the current interior and home textiles market.

7.3 Contributions

This practice-based research study combines the innovative Jacquard weaving technology, practical concept development and prototyping of illuminative smart home textiles. The developed prototypes are proven to provide positive benefits in energy efficiency and valuable theoretical and practical contributions to the field of textile design industry. Both fashion and textile design education can be profited as well as the knowledge of colour-changing smart home textiles from the aesthetic and functional perspectives. Besides, the developed high value colour-changing smart home textiles prototypes can be utilised in different types of textiles products and able to provide novelty in the contemporary textile industry.

7.3.1 Contributions in Theoretical Research

The theoretical design process model of illuminative smart home textile is developed based on the concept of a problem solving activity which is found in the field of engineering, architecture, product and industrial design. Different steps are identified in each design stage (see Figure. 3-7 p.60). The research design is divided into different stages namely, ‘research stage’, ‘analysis stage’, ‘design of initial prototypes’, ‘evaluation stage’, and ‘detail design’.

The ‘research stage’ consists of two steps, ‘needs’ and ‘identifying needs and explore; the ‘analysis stage’ is a feedback loop stage containing three steps, ‘analysis of problem’, ‘statement of problem’ and ‘conceptual design’; the ‘design of initial prototypes stage’ is also a feedback loop stage including two steps, ‘embodiment of schemes’ and ‘development of initial prototypes’; the final stage is ‘evaluation stage’ involving ‘detailing’ and ‘detail design’ to create the final colour-changing smart home textiles.

The developed design process model is important for designers and design students when creating new smart home textiles prototypes. Each step is able to assist designers and students to find the best solution for the design problem during the whole process.

The final smart home textile prototypes are created according to the developed theoretical design process model in this practice-based research study and it is significantly added to current knowledge with its approach in textile design field.

7.3.2 Contributions in Practical Research

The related technologies and applications of smart fashion and textiles design such as, various illuminative and colour-changing materials, specific sensors, weaving techniques and processes are created systemically in this research. Its corresponding prototypes are developed and created regarding to the selection of colour-changing materials, such as glow-in-the-dark yarn, LED lights, optical fibre, photochromic dye for smart home textiles. The integration of various sensors, such as pressure and radar detection sensor that can sense and detect changing environment for home textile products has achieved. Such contributions have not been made in the field of smart home textiles products. Five of the developed colour-changing smart home textiles prototypes can be utilised in different fields due to its ability to sense, react and be able to correspond to the changing environment.

The colour-changing material and technology used in creating the ‘Smart Cloth Sofa’ are ‘Glow-in-the-dark yarn’ and ‘pressure sensor’, respectively. Due to its pressure sensing function embedded into the woven fabric, it can be employed in the area of infant’s bedding. It can let infant sleep well in a comfort zone after feeding because the specific sound track will be turned on once an infant lying on the bedding. Also, it can be applied for entertainment purpose, for example it can be used to produce specific cushion toys with this technology for infants.

The technology used in the ‘Smart Curtain’ and ‘Smart Glass Mat’ can be used for restaurant and café’s table mat. When hot food and cold drink are put on the table mat or glass mat respectively, they will change colours due to their abilities of sensing the related heat and humidity for indication and safety purposes.

The ‘Smart Dining Table Cloth’ technology can be used as commercial purpose for decorating actual dining table and bar table found in a restaurant. Because of its illuminative effect of the optical fibres and embedded radar detection sensing function, it can be used as welcoming signage and creative decoration when guests are approaching the dining or bar table. An interaction between the people and the interior setting is established. Thus, a warm and friendly atmosphere is then created in the restaurant.

The colour changing smart materials can be widely used in the interior market as well as other purposes. It demonstrates that the colour-changing materials are able to assist people to make corresponding responses to different environments. In addition, it can also communicate with people by means by visual and audio media and the use of colour-changing materials can become an important application in current field of design.

7.4 Limitations of Study

There are certain limitations in this research study and they are as follows:

a) The 'Smart Cloth Sofa' is woven by the Glow-in-the-dark photonics yarn with 100% cotton yarn. Although the abrasion test is passed and its durability is acceptable. As the pressure sensor is packaged inside the woven fabric, the sofa cloth is not a washable product and the sensor will be damaged. Besides, The 'Smart Curtain' and 'Smart Glass Mat' are woven with 17 degree thermochromic yarn and 100% polyester yarn, both of them are not suggested to be washed as it may affect the thermal ability of the thermochromic yarn. Similarly, the 'Smart Lamp Cover' is not washable as it may affect the illuminative effect of the photochromic ink printed on the fabric. Most of the developed wearable electronics prototypes are not washable in the field of fashion and textiles (Schwarz et al, 2010).

b) The 'Smart Dining Table Cloth' is woven with 100% polyester yarn, 100% cotton yarn and optical fibre with basket weave structure. The pre-treated optical fibres illuminate and work very well with the inserted LED lights and with good interaction with the radar detection sensor, however due to the unbendable characteractics of the optical fibres, it is suggested to use hand loom machine to weave and it is suitable for producing large variety of similar products in terms of commercial purposes. "The optical fibre display has not yet reached the stage of market maturity and care properties of conventional textiles due to their construction" (Schwarz, 2010, p.169).

c) The 'Smart Curtain' is woven with 17 degree thermochromic yarn and 100% polyester yarn. The ability of releasing and storing energy of the thermochromic yarn will be limited with thousand times of cycles. Moreover, the 'Smart Lamp Cover' is woven with 100% polyester yarn with satin weave structure. Photochromic ink will change from clear to colour when activated by ultraviolet light, however the number of cycles is limited to thousands of times depending upon the application.

7.5 Implications for Future Research

An interior based smart home textiles prototypes are finally created by adopting the practice-based research methodology with full consideration of innovative Jacquard weaving technology, colour-changing smart materials, and application of sensors. However, there are implications for further research in this specific area and the implications are as follows:

a) To investigate the application of water-resistance weaving yarn in order to produce washable smart home textiles;
b) To study other specific weaving structures for optical fibres so as to create new smart fabric with more complicated design patterns by hand loom machine;
c) To examine other colour-changing materials similar to photochromic yarn and photochromic dye that can have longer lifecycle for developing longer lasting smart textiles; and
d) To explore other sensors that can be integrated into smart home textiles for sensing and responding to the changing environments.

To conclude, home textiles play a vital role in controlling the interior environment of a home and provide the texture, colour, character, scale, and anything that is missing in the architecture (Das, 2010). Smart fabrics are now more demanding than before. More fundamental research of smart fabrics is needed in the future in order to benefit the textile world and to create more smart products in the field of fashion and textile market (Cherenack & Pieterson, 2012). "Smart fabric, electronic textile, wearable computers, and smart material are all important in the growing field of microelectronics. The growth of this field is changing daily and what is expected for society will be different in the future compared to today" (Scharton, 2011, p.14).

APPENDIX I

Abrasion Resistance by the Martindale Method ASTM D4966

Abrasion Resistance ASTM D4966 Equipment Needed:

a) Martindale abrasion tester
b) Standard abradant fabric
c) Standard felt
d) Polyurethane foam backing
e) Fabric press cutters
f) AATCC Gray Scale for Color Change

Abrasion Test Procedure:

1. Sample Preparation: when cutting specimens, avoid wrinkles, folds or creases;
2. Avoid getting oil, water, grease, etc. on the specimens when handling;
3. Using the smallest cutting die, cut six circular specimens from the fabric to be tested with each specimen being 1.5 inches (38mm) in diameter. Take care not to apply too much pressure on the cutting die as it will break the razor blades;
4. Weigh one specimen to determine pre-test mass;
5. Also use this measurement to determine mass/unit area.

Preparation of the Abrasion Test:

1. Make all tests in the standard atmosphere for testing;
2. Remove the specimen holders from the Martindale tester by

a) Loosening and lifting off the black knobs on top of the tester;
b) Removing the silver covers held on by the black knobs;
c) Lifting the specimen holders out;

3. Note that all three parts of the specimen holders (handle, face, and ring) are numbered 1-6 and correspond to numbers on top of the Martindale tester;
4. Assemble the holder by:

a) Placing the cut specimen with the technical face down into the gold ring;
b) For specimens having a mass/unit area of less than 500 grams per square meter,
c) place a disk of polyurethane foam between the specimen and the metal face;
d) The face must sit flush and square inside the ring;
e) Screw the handle back on;

5. Place the assembled holders into the machine, replacing silver caps and black knobs;
6. Add the required weight (9kpa for apparel, 12kPa for upholstery) by resting the weights on the ends of the handles. (kPa = 1 kilo Pascal = # pounds) Note that the weights are also numbered 1-6;
7. Set the counter system to record the desired movements using the third black button from the right.

Starting the Abrasion Tester:

1. Turn the power on;
2. The machine should already be programmed to run a batch of 500 movements;
3. Push the green button to start the batch;
4. After the first batch is complete take specimen holders off of the machine and observe and record the results and changes in specimens;
5. Put specimens back on the machine and continue with the test
6. Observe and record the results after each batch of 500 movements until you have reached the desired number of movements (total of 3500); the end point if reached for a woven when two or more yarns have broken, or for a knitted fabric when a hole appears.

Abrasion Test Report:

1. State that the specimens were tested as directed in Test Method D4966.
2. Describe the material or product sampled and the method of sampling used.
3. Report the type of abradant and the mass of the weights used.
4. State the average number of movements required to rupture two or more yarns in woven fabric or develop a hole in a knitted fabric.

APPENDIX II

Operation Manual of Digital LUX METER

Operation Instructions:

1. Connect the battery, and then press the button to “ON”
2. Press the range selection switch to desired range.
3. Remove the photo detector cap and face it to light source in a horizontal position.
4. Read the test value from the LCD display.
5. Over range: if the instrument only display one “1” in the M.S.D., the input signal is too strong, and a higher range should be selected.
6. Data-Hold mode: press the HOLD key to select Hold model. When HOLD mode is selected, the LUX meter stops all further measurements and the test value with hold on the LCD. Press the button “HOLD” to the “ON”, the hold value will be cancelled.
7. When the measurement is completed, replace the photo detector cap and turn the power selector OFF.

Battery Check-up & Replacement:

1. It is necessary to replace another one 9V battery, when left corner of LCD display show “ + − ”.
2. After turning off the meter, press the battery cover and push in the direction of the arrow to open.
3. Disconnect the batter from the instrument and replace it with a standard 9-volt transistor battery and go for the cover.

Spectral Sensitivity Characteristic:

Maintenance:

1. The white plastic disc on the top of the detector should be cleaned with a damp cloth when necessary.

2. Do not store the instrument where temperature or humidity is excessively high.
3. The reference level, as marker on the face plate, is the tiof thep photo detector globe.
4. The calibration interval for the photo detector will vary according to operational conditions, but generally the sensitivity decreases in direct proportion to the product of luminous intensity by the operational time. In order to maintain the basic accuracy of the instrument, periodic calibration is recommended.

Recommended Illumination:

OFFICE	Conference, reception room	200~750Lux
	Clerical work	700~1,500Lux
	Typing drafting	1,000~2,000Lux
FACTORY	Packing work, entrance passage	150~300Lux
	Visual work at production line	300~750Lux
	Inspection work	750~1,500Lux
	Electronic parts assembly line	1,500~3,000Lux
HOTEL	Public room, cloakroom	100~200Lux
	Reception, cashier	220~1,000Lux
STORE	Indoors stairs corridor	150~200Lux
	Show window, packing table	750~1,500
	Forefront of show window	1,500~3,000
HOSPITAL	Sickroom, warehouse	100~200Lux
	Medical examination room	300~750Lux
	Operation room, emergency treatment	750~1,500Lux
SCHOOL	Auditorium, indoor gymnasium	100~300Lux
	Class room	200~750Lux
	Laboratory, library, drafting room	500~1,500Lux

APPENDIX III

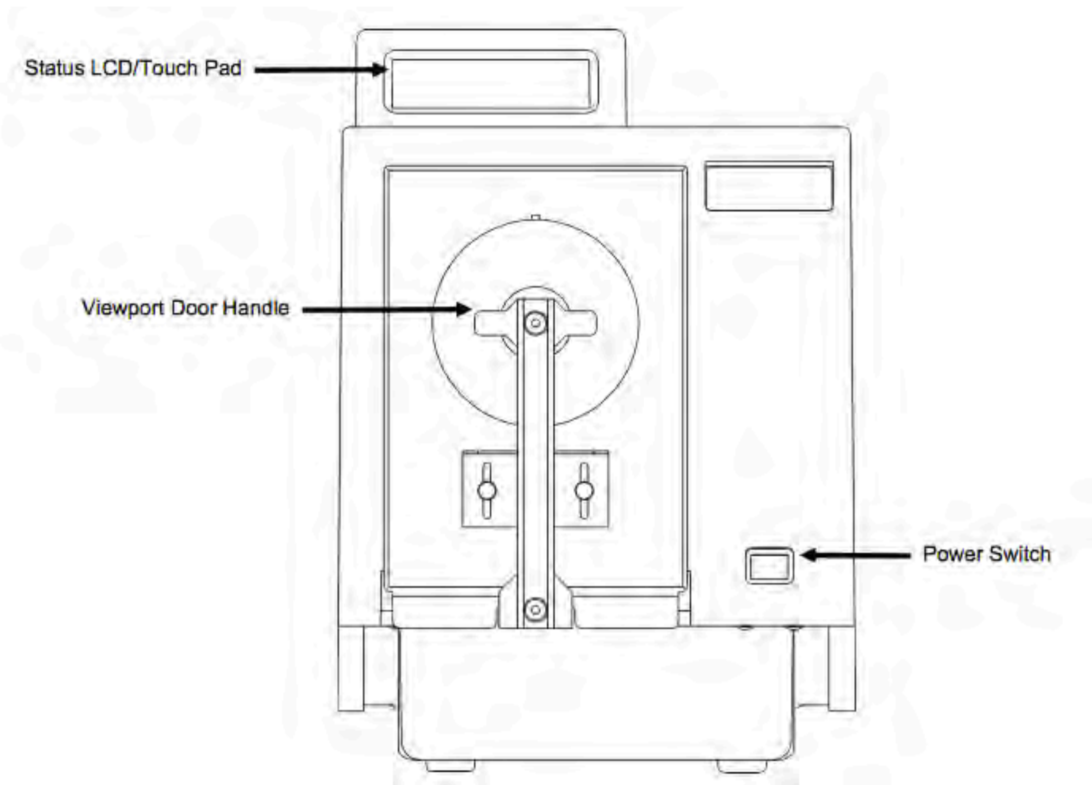
Colour-Eye 7000A Operation Manual

Operation General:

This section describes how to turn the instrument on and off, install the Specular Component Excluded (SCE) light trap, retaining lever, thin film sample and cuvette holders, change the sampling aperture, and use the viewport door release.

Power On-Off Switch:

The CE-7000A AC power on-off switch is located on the front of the instrument. (See below Figure). Press the left end of the rocker switch to apply AC power. To remove AC power from the unit press the right end of the rocker switch. A lamp located inside the switch lights when AC power is applied. The instrument is ready to use when you hear a short beep after power up. If the instrument does not respond to power up, check power connections to the unit and main power availability (breakers, fuses). If these connections are all right, check the unit's fuses. Refer to "Fuse Replacement" in Section 5.



Calibrating the Spectrophotometer:

The Color-Eye 7000A spectrophotometer needs to be calibrated with the white ceramic calibration tile provided with the unit. It is best to calibrate the instrument at the location it is to be used. This will accommodate ambient temperature changes.

Before you Calibrate...

Please note the following before you calibrate the spectrophotometer:

- Calibration is required every 8 hours. It is a good practice to calibrate hourly.
- If the instrument is exposed to rapid changes in ambient temperature, calibrate to accommodate for these changes.
- Make certain that the serial number on the White Ceramic Calibration Tile is the same as the serial number on the instrument. Do not substitute another calibration tile for the one originally supplied.
- If the tile should be broken or become damaged, call X-Rite for advice on how to replace it.

Reflectance Calibration Procedure:

1. Touch and release Cell 5 on the Main Menu Display until the desired specular component status (SCE/SCI) is displayed.
2. Select the desired sampling aperture. Refer to “Changing the Sampling Aperture” later in this section.
3. Use the software program to select reflectance mode.
4. Place the Zero Calibration Standard facing the unit so that it completely covers the viewport opening.
5. Use the software program to initiate the zero (black) calibration.
6. Place the White Calibration Tile facing the unit so that it completely covers the viewport opening.
7. Use the software program to initiate the white tile calibration.
8. After calibration return the white calibration tile to it storage area.

Transmission Calibration Procedure:

1. Touch and release Cell 5 on the Main Menu Display until Specular Component Included is displayed.
2. Select the Large Area of View (LAV) sampling aperture and Large Area of View (LAV) Zoom Lens position. Refer to “Changing the Sampling Aperture” later in this section.
3. Place the Spectralon Calibration plaque facing the unit so that it completely covers the viewport opening.
4. Install the Thin Film / Transmission sample holder. (If a cuvette is to be used, insert a clean cell filled with distilled water in its holder.) Refer to “Using the Thin Film Sample Holder” later in this section.
5. Use the software program to select transmittance mode and initiate the calibration.
6. After calibration, leave the Spectralon Calibration plaque in the viewport for the remainder of the measurements.

REFERENCES

Abrasion Resistance by the Martindale Method. (2004). Retrieved from http://www.uni.edu/csbs/sites/default/files/Abrasion_Resistance-Martindale.pdf. Accessed on 20th June, 2015.

Alexander, V.B., Anselm, E., Hermann, J., Peter, K., & Jochem, K. (1998). Pressure & Temperature Measur ement (U.S. Edition). WIKA Instrument Corporation.

Anderson, K. (2005). Smart Textile Update, Retrieved from http://www.techexchange.com Accessed on 2nd May, 2013.

Anton, B. (2007). Light-emitting Diode. Retrieved from http://www.lightsandknives.com/led-technology-history.htm. Accessed on 29th April 2013.

Archer, L.B. (1969). The structure of the design process, Design Methods in Architecture, Lund Hamphries, London.

Archer, L. B., 1984, Systematic Method for Designers. In: N. Cross (Ed.), Devel-opments in Design Methodology, Wiley, Chichester.

Baldy, C. (2008). Making Photochromic History: The Next Generation of Technology 2012. Retrieved from http://www.bretoncom.com/vision/2002/03/09.asp. Accessed on 1st October, 2012.

Baser, G. (2008). Engineering approach to industrial design of woven fabrics, International Journal of Fashion Design, Technology and Education, 1(2), 79-87.

Baurley, S. (2004). Interactive and experiential design in smart textile products and applications. Cambridge, UK: Pourdeyhimi.

BMW, (2011). Geneva Motor Show BMW. Retrieved from http://www.bmwblog.com/2012/01/25/bmw-to-use-touch-sensitive-smart-fabric-in-cars/. Accessed on 1st October, 2012.

Candy, L. (2006). Practice based research: A guide. CCS Report V1.0, pp.1-19. University of Technology, Sydney.

Chapman, W.L., Bahill, A.T., & Wymore, A.W. (1992). Engineering modeling and design. Boca Raton: CRC Press.

Cherenack, K.H. & Pieterson, L. van. (2012). Smart textiles: Challenges and opportunities. Journal of Applied Physics 112 (9), 091301.

Color-Eye 7000A Spectrophotometer. (2013). Retrieved from https://www.xrite.com/documents/manuals/en/gmb_7000a_manual-en_en.pdf. Accessed on 20th June, 2015.

Cross, N. (1994). Engineering design methods: strategies for product design. John Wiley, Chichester.

Colour-changing Material: Photochromic. Retrieved from http://www.colourchange.com.cn/main_en.asp. Accessed on 1st October, 2012.

Creager, C. (2006). All About Weaving. Huddersfield, UK: University of Huddersfield Journal Press.

Curden, E.,Fahlen, T., & Bulin, G. (2015). Art Suite: Time Piece. Retrieved from http://www.icehotel.com/art-and-design/this-years-artists/. Accessed on 30th June 2015.

Darke, J (1978). The primary generator and the design process. New Directions in Environmental Design Research: proceedings of EDRA 9, EDRA, Washington, 325-337.

Darke, J. (1979). The primary generator and the design process. Design Studies 1(1), pp.36-44.

Dorst, K., & Dijkhuis, J. (1995). Comparing paradigms for describing design activity. Design Studies, 16, 261-274.

Das, S. (2010). 3 Fibres and fabrics used in home textiles: Performance of Home Textiles. Woodhead. India.

Erickson, B. (2009). Self-Darkening Eyeglasses: The science behind dual-purpose lenses. American Chemical Society Journal of Science and Society, Science &

Technology, 87(15), p.54.

Ernevi, A., Jacobs, M., Mazé, R., Müller, C., Redström, J., & Worbin, L. (2012). Interactive Institute, Swedish. Solar Energy Curtain. http://www.tii.se. Accessed on 28th April, 2013.

Ehrlenspiel, K., & Dylla, N. (1993). Experimental Investigation of Designers Thinking Methods and Design Procedures, Journal of Engineering Design, 4(3), 201-212.

Fahy, F. (1989). Sound intensity. Elsevier Applied Science. London.

Findmeagift Ltd, (2010). Color Changing Moonlight Cushion. Retrieved from http://www.findmeagift.co.uk/gifts/colour-changing-moonlight-cushion.html. Accessed on 29th April, 2013.

French, M. (1985). Conceptual Design for Engineers, Design Council, London.

French, M. (1999). Conceptual design for engineers (3rd Edn.). London: Springer.

Gardner, C. (2005). The use and misuse of coloured light in the urban environment. Optic & Laser Technology, 38(4), pp.366-376.

Gauvreau, B., Guo, N. , Schicker, K., Stoeffler, K., Boismenu, F., Ajji, A., Dubois, C., & Skorobogatiy, M. (2009). Colorful photonic band gap fiber-based textiles.

Conference on Lasers and Electro-Optics and 2009 Conference on Quantum electronics and Laser Science Conference, pp.1-2.

Goerner, D. (2009). Woven Structure and Design. London. Textiles Museum.

Gokarneshan, N., & Dhannapal, P. (2007). Technology of Illuminative Fabrics, Journal of the Textile Association, 641(6), pp.267-269.

Green, R.E. (1980). Acoustics: Historical and Philosophical Development. Lindsay, R.B. (ED), R. S. Shankland Reviewer. pp.2-8. Dowden, Hutchinson & Ross.

Halsey, M., & Youngmark, L. (2007). Foundation of Weaving. Yorkshire: University of York.

Harlin, A., Myllymäki, H., & Grahn, K. (2002). Polymeric Optical Fibres and Future Prospects in Textile Integration. Journal AUTEX Research, 2(3), pp.139.

Held, S. E. (2009). Weaving: A handbook of the Fiber Arts. Huddersfield: University of Huddersfield Journal Press.

Held, S.E. (1978). Weaving: A handbook of the Fiber Arts. London: Holt, Rinehart and Winston.

Harris, T., & Fenlon, W. (2011). How Light Emitting Diodes Work. Retrieved from http://www.howstuffworks.com/led.htm. Accessed on 3rd June, 2013.

Hilhorst, D., & Zambetti, N. (2007). Pillow remote control. Retrieved from http://studio.droog.com/studio/all/smart-deco-2/cushion-control-by-didier-hilhorst---nicholas-zambetti. Accessed on 29th April, 2013.

Hillier, B., Musgrove, J., & O'Sullivan, P. (1972). Knowledge and Design. In W, Mitchell (Ed.), Enviromental Design: Research and Practice. Los Angeles: Univerity of California.

Hooper, L. (1979). Hand-Loom Weaving. London: Pitman ; Taplinger.

Ice Hotel (1989). The Story of Ice Hotel. Retrieved from http://www.icehotel.com/about-icehotel/. Accessed on 4th July 2014.

Neidlinger Polakoff., J, Berzowska., & Skorobogatiy, M. (2010). An interactive garment with integrated silk & photonic band-gap fiber woven strips concealed within pleats. Research Journal of Textile and Apparel, 14, p. 97.

Woodhead Publishing Limited (2013). Innovative jacquard textile design using digital technologies. Chapter 1, pp.1-7 Introduction to jacquard textile design.

Jacquard Weaving Inventor and History. Retrieved from http://www.ferdinando.org.uk/jacquard.htm. Accessed on 3rd June, 2013.

Jones, J.C. (1970). Design methods: Seeds of human futures. New York: Wiley-Interscience.

Jordan, P. (2004). Recent developments in practice-based/led research in art and design. All Ireland Society for Higher Education inaugural Conference 2004.

Jones, J.C. (1984). A method of systematic design. In N. Cross (Ed.), Developments in design methodology (pp.9-32). New York: John Wiley.

Jacquard, J.M. (1752). Retrieved from http://www.britannica.com.ezproxy.lb.polyu.edu.hk/EBchecked/topic/299152/Joseph-Marie-Jacquard. Accessed on 3rd June, 2013.

King, D.A. (1994). Curling in the heat. Nature, 368(6473), p.689.

Konstanze, A. (2013). Liquid iridescence – Structural Color fashion by Amy Winters. Retrieved from http://www.rainbowwinters.com/project6.html. Accessed on 29th April, 2013.

Laurysen, Y. & Mantel, E. (2009). LED cell carpet. Retrieved from http://www.lamaconcept.nl/collection/cell/led.html. Accessed on 28th April, 2013.

Lawson, B. (1980). How designers think. The Architectural Press Ltd. London, 30-32.

Lawson, B. (1997). How Designers Think, The design process demystified completely rev.3rd ed. Architectural Press Ltd. Kent, UK.

LCR Hallcrest, (2006). Photochromic Retrieved from http://www.colorchange.com/photochromic. Accessed on 3rd June, 2013

Legro, W. (2010). Haute Tech LED-coat. Retrieved from http://studiowm.com/Exhibitions. Accessed on 29th April, 2013.

Ligorano, N. & Reese, M. (2012). Fiber Optic Tapestry. Retrieved from http://ligoranoreese.net/fiber-optic-tapestry/. Accessed on 29th April, 2013.

Lindsay, R.B. (1964). Lindsay's wheel of acoustics. J. Acoust. Soc. Am. 36: 2242.

Liu, Y., Gorgutsa, S., Santato, C., & Skorobogatiy, M. (2012). Effects of additives on the properties of electrodes. Journal of The Electrochemical Society, 159 (4), pp.349-356.

Luk, C.H. (2011). Sound Illuminating Dress. Retrieved from http://chunghay.com/sound-illuminating-dress. Accessed on 29th April, 2013.

Luminous, S. Glow-in-the-dark pinstrips. Retrieved from www.scheller-textiles.com. Accessed on 3rd June, 2013.

Mary, E. Black. (2008). The Key to Weaving. Huddersfield, UK: University of Huddersfield Journal Press.

Manich, A. M., De Castellar, M. D., & Sauri, R. M. (2001). Abrasion kinetics of wool and blended fabrics. Textile Research Journal, 71, 469–474.

Maver, T. W. (1970). Appraisal in the building design process, in G Moore (ed) Emerging Methods in Environmental Design and Planning, MIT. Press, Cambridge, Mass, 195-202.

MCR Safety. (1996). Illuminated Work Gloves. Retrieved from http://www.mcrsafety.com/index.php/gloves/. Accessed on 3rd June, 2013.

Mertens, R. (1998). Organic Light-emitting Diode. Retrieved 2012 from http://www.oled-info.com/introduction. Accessed on 3rd June, 2013.

Mertens, R. (2013). The OLED Handbook 2013 Edition. Lulu Enterprises Inc. Israel.

Murray, R. (2008). The Essential Handbook of Weaving. Huddersfield: University of Huddersfield.

Neidlinger, K. (2010). GER – emotional fashion. Retrieved from http://www.fashioningtech.com/profiles/blogs/ger-galvanic-extimacy. Accessed on 29th April, 2013.

Ng, F. & Zhou, J. (2013). Innovative Jacquard Textile Design Using Digital Technologies. Principles and methods of digital jacquard textile design. Woodhead Publishing Limited, U.K.

New Prismatic Co., LTD. (2008a). Long Lasting Glow in the Dark Material. Retrieved 2012 from http://www.colorchange.com.tw/english/index.php/long-lasting-glow-in-the-dark-material.html. Accessed on 1st October, 2012.

New Prismatic Co., LTD. (2008b). Photochromic Material. Retrieved from http://www.colorchange.com.tw/english/index.php/photochromic-material.html. Accessed on 1st October, 2012.

Orth, M. (2003). Materials Research Society. Journal of Defining Flexibility and Sewability in Conductive Yarns, 736(4), p.11.

Pahl, G., & Beitz, W. (1996). Engineering design: A systematic approach, 1996, PhD thesis, University of Cambridge, UK.

Polakoff, M. (2010). Show of the night– color explosion on your dress. Retrieved from http://www.fashioningtech.com/video/voice-following-dress. Accessed on 29th April, 2013.

Pourdeyhimi, B. (2006). Printing electric circuits onto nonwoven conformal fabrics using conductive inks and intelligent control. National Textile Center Annual Report, USA.

Rohde & Schwarz, (2012). Introduction to Radar System and Component Tests. Retrieved from http://www.rohde-schwarz.se/file_18640/1MA207_0e.pdf. Accessed on 3rd July, 2014.

Scaturro, F., & Genz, R. (2010). U2 Leather Jackets. Retrieved from http://www.cutecircuit.com/u2-leather-jackets/. Accessed on 28th April, 2013.

Satomi, M., & Wilson, H.E. (2012). Weaving Conductive Fabric, ITM COLLECTION. Retrieved from http://www.kobakant.at/?p=432. Accessed on 3rd June, 2013.

Scaturro. (2009). Embrace-me Hoodie. Retrieved from http://www.5050ltd.com/embrace_me.php. Accessed on 3rd June, 2013.

Scharton, D. A. (2011). Survey of Research Literature in Information Technology Planning and Delivery .The importance of smart fabric in future technology, Capella University.

Schoeller, (2009). Schoeller's Jacket under Light. Retrieved from http://www.schoeller-textiles.com. Accessed on 3rd June, 2013.

Schicker, K. (2009a). Interactive Wear, Zegna Sport Freeway Jacket. Retrieved from http://www.interactive-wear.de. Accessed on 28th April, 2013.

Schicker, K. (2009b). IntertechPira Smart Fabrics conference, Puma Basket CC Sneakers. Retrieved from http://www.puma.com. Accessed on 28th April, 2013.

Schicker, K. (2009c). IntertechPira Smart Fabrics Conference. Design-led smart textiles, Studio 5050, Embrace-Me Hoddies. Retrieved from http://www.5050ltd.com. Accessed on28th April, 2013.

Schicker, K. (2009d). IntertechPira Smart Fabrics Conference. Illuminating and Color changing Clothing, Airbone Dress. Retrieved from http://www.nyxit.com. Accessed on 28th April, 2013.

Schicker, K. (2009e). IntertechPira Smart Fabrics Conference. Retrieved from http://www.intertechpira.com. Accessed on 28th April, 2013.

Schicker, K. (2009f). Photonic Textiles Workshop. Retrieved 2012 from http://www.photonics.ohy.polymtl.caa. Accessed on 28th April, 2013.

Schon, D.A. (1990). The design process. In V.A. Howard (Ed.), Varieties of thinking: Essays from Harvard's philosophy of education research center (pp.110-141). New York: Routledge.

Schwarz, A., Langenhove, L.V., Guermonprez, P., & Deguillemont, D. (2010). Electric Plaid, colouring-changing textile wall panels, Journal of Textile Progress, 42(2), pp.99-180.

Seung, (2010). Pillow Alarm. Retrieved from http://www.coroflot.com/Design-jay/Alarm-Pillow. Accessed on 29th April, 2013.

Sjardijn , D. (2010). The magical illumination of a carpet. Retrieved from http://prettysmarttextiles.com/exhibition2010/.Accessed on 29th April, 2013.

Takala, R., Keinonen, T., & Mantere, J. (2006). Processes of Product Concepting, Springer London: London, pp.58-78.

Tao, X.M. (2005). Wearable Electronics and photonics. Hong Kong: The Hong Kong Polytechnic University.

The IMI and the EPSRC Smart Textiles Network. (2006). Light emitting Textiles for Fashion and Health, p.2.

The Interactive Design Institute in Sweden. (2010). Retrieved from http://www.tii.se. Accessed on 2nd May, 2013.

The Schoeller Textil AG Switzerland. Retrieved from http://www.schoeller-textles.com. Accessed on 2nd May, 2013.

Torben, L (1996) Responsive (smart) materials, Colour changing materials, Detco Enterprise: USA.

Wagner, P. (2009). Berit Greinkes MA project: Sound/pattern: pattern/sound. Retrieved from http://www.textilefutures.co.uk. Accessed on 2nd May, 2013.

Wagner, P. (2008). Fractal Living Jewellery. Retrieved from http://www.design.philips.com/about/design/designportfolio/design_futures/fractal.page. Accessed on 28th April, 2013.

Watkins, P. (2005). Avantex Symposium: Electronics + Textiles. WGSN, LD.

Winter, R., Griffiths, M. & Green, K. (2000). The academic qualities of practice-based PhD? Studies in Higher Education 25(1), pp.25-37.

Won, R. (2008). Nature Photonics, Photonic-bandgap fibre: Colour-tunable textiles. 2(11), p.650.

X-Rite Incorporated, (2013). THE CIE Colour Systems. Retrieved from http://www.xrite.com/documents/Literature/EN/L11-029_Color_Guide_EN.pdf. Accessed on 4th August, 2014.

Zainzinger, E. (2012). Smart Fabrics – BMW gives a makeover to old fashion car interior. Retrieved from http://www.talk2myshirt.com/blog/archives/5445?utm_campaign=fromtwitter&utm_medium=twitter&utm_source=twitter. Accessed on 1st October, 2012.