Designing nonwovens: craft and industrial perspectives

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Designing Nonwovens: Craft and Industrial Perspectives

by

Faith Kane

Doctoral Thesis

Submitted in partial fulfillment of the requirements

for the award of

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August 2007

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Abstract

Nonwovens form a significant and rapidly growing sector of the textiles industry. The nonwovens sector originally set out to provide economical alternatives to traditional textiles for functional product components such as interlinings and carpet backings. Through constant growth and development nonwovens are now considered as sophisticated engineered fabrics that economically meet specific functional needs. Since the 1970's, however, the potential to use nonwoven fabrics and technologies within design has been under consideration by textile researchers, textile artists and fashion and textile designers and makers. The resulting fabrics have found application in mass marketable products such as gift and flower wrap and as one-off designer products such as scarves. In comparison to traditional sectors of the textile industry such as woven textiles, however, in regard to design there seems to be little middle ground between these two production contexts. Further to this, the range of nonwoven technologies that have been explored by textile designers, makers and artists is relatively limited and focuses predominantly on the needle-punching method of manufacture to produce felt-like fabrics. This situation presents a potentially missed opportunity within the nonwovens sector of textile manufacture.

The research presented in this thesis aims to identify and explore the undeveloped opportunities to design nonwoven materials from an aesthetic perspective using a specific range of production processes and materials. The work is set within the context of designer maker practice and as such considers both industrial and craft perspectives on the design and manufacture of nonwovens. In doing so the relationship between craft and industry within the sphere of nonwovens is brought into question and the opportunities and limitations of working as a designer maker within this sphere are explored. The development of textile products for niche, high-end markets is of growing importance within the European textiles industry. This research explores the potential to develop design-led nonwovens for high-end markets.

The work was conducted using a practice led research approach which revolved around the development of innovative new fabrics suitable for high-end markets. The work focuses on the use of carding, needle-punching and thermal bonding technologies that utilize heat and pressure and subsequent decorative finishing processes including devoré, embossing and laser cutting. The ability to design nonwoven fabric structures specifically for use in these processes formed a central part of the contribution to knowledge made within the work. In particular, the development of devoré and laser techniques for nonwovens made from contrasting fibre layers or with decorative materials embedded within them. The fabrics produced evidence new design concepts within the sphere of nonwovens. The suitability of the designs for production within different manufacturing contexts was assessed through a series of interviews with nonwoven manufacturers and their suitability for the high-end markets was evaluated through a series of focus groups and interviews with textile and product...
designers. The qualitative nature of the analysis made provides a new perspective on the design value of nonwovens. The results of the research confirmed the aesthetic appeal of certain fabrics within the collections produced and their suitability for high-end markets. The findings identified key factors in regard to how value is attributed to nonwovens within this market and suggested that further research into developing high-value nonwovens is required. The work identified key issues that designers working with nonwoven technologies need to be aware of to enable designs that are relevant for commercialization to be developed.
I would like to thank the following people for their help and support in completing the research for this thesis: Kerry Walton and Professor Terence Kavanagh for their supervisory guidance and continued support and encouragement; Zarei Akbar, Manoj Rathod, Sally Yates, Dave Gibbs, Matthew Broughton, Alan Duncan, Angela Davies and Peter Wileman for technical support; the Centre for Materials Research and Innovation at Bolton University and the Nonwovens Research Group at Leeds University for allowing access to machinery; all companies who provided materials and access to machinery, in particular Lenzing, Wellman International and Texon UK; all interview and focus group participants; Carl Woodhatch, Kerry Walton, Professor Terrance Kavanagh and John Williams for reading thesis drafts and; finally my family for their support and patience, in particular my husband Tom and my Grandmother and Grandfather, Gladys and Joseph Pace.
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Chapter 1

1.1 Research Aim and Context

The purpose of the research presented in this thesis is to identify and explore the undeveloped opportunities to design nonwoven materials from an aesthetic perspective using a specific range of production processes and materials.

The work is set within the context of designer-maker practice and aims to identify the opportunities and limitations of working as a designer-maker within the sphere of nonwovens. This is addressed by developing a body of innovative nonwoven designs and assessing the potential to manufacture them on a number of production levels. In doing this the work brings into question the relationship between craft and industry in regard to nonwovens, thus considering craft and industrial perspectives on designing nonwovens.

This introductory chapter outlines the research background and the research questions, provides an overview of methodological approach taken within the research, gives a chapter by chapter summary of the thesis content; summarises key delimitations and introduces the contribution to knowledge made through the work.

1.2 Research Background and Questions

1.2.1 Nonwovens

The nonwovens industry forms a significant and rapidly growing aspect of the textiles sector. The industry originally set out to provide economical alternatives to traditional textiles for functional product components such as interlinings and carpet backings. However, through the constant growth and development of the industry, nonwovens are now considered as sophisticated engineered fabrics that economically meet specific functional needs (Batra et al, 1999). They are used in medical textiles, architectural and geo-textiles, domestic and personal hygiene products, fashion, art and performance wear. Nonwovens are predominantly applied within these areas as component parts performing unseen or technical functions but are increasingly employed as visible surfaces providing aesthetic appeal.

The term ‘nonwoven’ implies something that is simply not woven, however, there are a number of precise definitions that give specific details as to what a ‘nonwoven’ actually is. The British Standards (BSI, 1992) definition states that a nonwoven is:

"A manufactured sheet, web or batt of directionally or randomly orientated fibres, bonded by friction, and/or cohesion and/or adhesion, excluding paper and products which are woven knitted, tufted, stitch-bonded incorporating binding yarns or filaments or felted by wet-milling whether or not additionally needled. The fibres may be of natural or man-made origin. They may be staple or continuous filaments or be formed in situ"
The processes and materials used to make nonwovens, and the qualities of the end products themselves, link them to the chemicals, plastics, felt and papermaking industries (Wilson, 2007, p.4-5.). Although there are similarities with these industries and products with nonwovens, the various elements of nonwoven production create a unique industry and products with specific and unique properties.

1.2.1.1 Nonwovens and Design
Wilson (2001, p.2) highlights that design decisions are made at every stage of the textile manufacturing process and that these decisions may be made by engineers and technologists or designers trained in aesthetics. In regard to nonwovens, due to their end use applications and markets, design decisions are usually made by engineers and technologists as performance requirements are paramount. The notion of using nonwoven fabrics for aesthetic purposes and thus approaching nonwoven manufacture from an aesthetic perspective is, however, not new. Since the 1970's the potential to use nonwoven fabrics and technologies within design has been under consideration by textile and fashion researchers, textile artists and textile designers and makers (Marsden 1977, Geesin 1995, Bartlett 1997, Tait 2004, Appleton and Yoshimoto 2004, MacFarlane 2005, University of Leeds, 2007). The resulting fabrics have found application in mass marketable products such as gift and flower wrap and as one-off designer products such as scarves for niche markets. In comparison to traditional sectors of the textile industry such as woven textiles, however, in regard to design there seems to be little middle ground between these two production contexts. Further to this, the range of nonwoven technologies that have been explored by textile designers, makers and artists is relatively limited and focuses predominantly on the needle-punching method of manufacture to produce felt-like fabrics. This situation poses a potentially missed opportunity within the nonwovens sector of textile manufacture.

The research presented within this thesis addresses this potential opportunity. Owing to the researchers initial interest in heat bondable fibres the research focuses on thermal bonding technologies but also looks at aspects of chemical bonding and needle-punching.

It centres on the use of thermal and mechanical bonding techniques alongside decorative finishing processes to develop new nonwoven fabrics for high-end markets. As noted previously, the work is set within the context of designer-maker practice. To clarify this approach to textile production, an overview of different modes of textile design and manufacture is summarised below.
Chapter I: Introduction

1.2.2 Textile Design and Manufacture

Within most areas of textile production, manufacture spans craft and industrial spheres. Traditionally, industrial production has been equated with mass manufacture and is often linked to mid volume or lower market areas (Wilson, 2001, p.1). In contrast to industrial production, craft systems of production are equated with hand-based or low technology processes (Wilson, 2001, p.1). Within these spheres various modes of design practice exist.

1.2.2.1 Textile Design Practice for Industry

In traditional areas of textile manufacture such as woven and knitted textiles, industrial and craft methods of textile manufacture are inextricably linked through design. Traditionally, the textile designer produces designs in the form of fabric samples (or swatches) using hand-based or relatively low technology processes. Through the sampling process, a series of fabric designs is produced along with technical specifications which enable the design to be reproduced industrially. Designers working in this way produce fabrics for low, middle and high-end market sectors. The majority of fabrics and textile products produced are, as Wilson (2001, p.9) notes, sold in the middle volume or mass market area and in the lower or down-end market areas. In relation to this mode of production it must be noted that computer software has been developed in most areas of textile manufacture enabling designs and specifications to be developed digitally.

1.2.2.2 Textile Craft Practice

Craft practice within textiles informs design for industry but also functions as a distinct category of textile practice. Gale and Kaur (2002, p.63) write that textile craft practice is 'commonly perceived as multi-media, exploring the inherent qualities of different textile materials' and that a 'craft approach to textiles is very much process-led; the actual pursuit of making by hand is of paramount importance'. The nature of hand work enables personal interaction with the making process and an instinctive response to materials which is central to design within craft practice. Textile products produced through craft practice usually function in niche, high-end market areas due to their exclusivity. They derive their value, as Yair (2001, p. 78) notes, from a sense of quality, tradition and customisation.

1.2.2.3 Textile Designer-Maker Practice and Class Production

Since the 1980's the notion of 'designer-maker' practice has become established (Taylor, 2001). The term designer-maker is applicable to a range of design disciplines including Textiles. Designer-maker practice can be described continuum between industrial design practice and craft practice and involves the interaction of designing, making and manufacturing in a small business setting. Designer makers usually produce batches of
products and, whilst a craft approach to design often informs the development of prototypes, the products themselves are often subcontracted to industrial manufacturers or taken on by major retailers (Gale and Kaur, 2002, p.50). This differs from craft practice in that full control is not maintained by the maker but rather negotiated with industry. Like craft products, designer-maker products function within niche, high-end markets and, as Gale and Kaur (2002, p.50) note, they often demonstrate the craft origins of their design which contributes to their value.

In regard to textile design and manufacture Jack Lenor Larsen (1989, p.39) proposes another mode of textile design practice and manufacture that essentially considers a continuum between craft and industrial production. He notes a danger in polarising textile making as either the pursuit of 'one-off' or 'mass produced' goods and has developed a philosophy of production that integrates the two. He terms this philosophy 'class production' and states that it revolves around the production of luxury fabrics, in small runs that are fuelled by an innovative and creative approach to manufacture. The fabrics produced function in high-end market areas.

As textile production for the mid-volume and mass market areas is becoming increasingly competitive due to the ability of offshore manufacturers to provide cheap production, as Ronald Weisbrod (2003, p.2), noted in his paper 'European Textile Designers in a Changing Global Environment', the development of textile products for niche, high-end markets is of growing importance within the European textiles industry. Within the context of a growing and diversifying nonwovens industry, this research questions whether a mode of production that relates to designer-maker practice and class production is relevant within the nonwovens sector.

1.2.3 Research Questions
The research questions stem from the central proposal that;

By establishing a mode of design practice that i) pursues the development of nonwoven fabrics for design purposes through hands-on interaction with nonwoven technologies (in other words by pursuing a craft approach to design) and ii) explores the practical and contextual limitations of industrial production, new fabrics can be achieved and links between designers and industry can be built, thus expanding the application of nonwovens within high-end textile markets.
In order to investigate this, the following questions were asked:

1. What aspects of industrial nonwoven technologies can be appropriated using hand-based textile processes?
2. What aspects of pilot scale carding and thermal bonding production processes that utilise heat and pressure can be manipulated for design/aesthetic purposes?
3. How can printing, embossing, laser cutting and marking processes be used to add further aesthetic value to the fabrics produced?
4. Are the fabrics produced suitable for high-end markets, and in particular interior products?
5. What opportunities and limitations exist for producing such fabrics within the context of the nonwovens industry?

1.3 Methodology

Within the textiles sector, new products are designed and developed by engineers, technologists and designers. The methods used by each are often different (Wilson 2001, Kroes 2002, and Broadbent 2003). The methodological approach taken within this research has been informed by the focus on the aesthetic aspect of textile design and the researcher's educational background. Designing and making is central to the research aim and questions, therefore, the selection of a methodological framework that allows creative practice to be integral to the work was a guiding factor in developing the approach taken.

1.3.1 Methodological Framework

Methodological frameworks in which creative practice is central have been developed, established and argued in recent years (Gray and Malins, 2004). The adaptation of Naturalistic Inquiry, a methodological framework originally established within the social sciences by Guba and Lincoln (1985), by art and design researchers (Bunell, 1998), is an example of such a framework. This framework was selected for use in this research because it acknowledges the centrality and impact of the researcher on the research results, specifies that research takes place in a natural rather than controlled environment and enables a creative dynamic to be central to the work by allowing ideas, methods and theory to emerge throughout the course of the research.

1.3.2 Methods

Within the framework of Naturalistic Inquiry, a number of methods were used to enable each of the research questions to be appropriately addressed.
Chapter 1

1.3.2.1 Practical Research
Reflective Design Practice was developed as the main method for practical investigation and was used to address Questions One, Two and Three. This method was based around Donald Schöen's (1983) notion of Reflective Practice and traditional notions of Experiment. The reflective aspect of this method involved personal reflection in and on the researcher's design practice (within the context of the research). Schöen (1983, p.vii), explained that such reflective practice, provides a way of understanding, making explicit and developing the 'know how' used in and gained through professional activity. The method was experimental in that 'explicit rules' relating to traditional notions of experiment were developed and adhered to. This provided a balance between creative exploration and systematic documentation and rigor. Within this method, a craft approach to design was taken in which designing and making were integrated through personal interaction with materials and processes. Literature reviews also informed and underpinned the direction of the practical research.

Work Undertaken
Four stages of practical research were undertaken. Stage One was, in some ways, rudimentary and involved the development and exploration of hand-based methods of nonwoven production. This enabled the researcher to develop a hands-on understanding of nonwoven materials and processes and formed the foundations for the subsequent work. Stage Two involved the development of design ideas using pilot scale nonwoven equipment. This enabled the design opportunities and limitations, from an aesthetic perspective, of specific nonwoven technologies to be identified. It also enabled the researcher to develop sensitivity to industrial manufacture. In Stage Three, various decorative finishing processes were explored in relation to the fabrics produced. In Stage Four, the knowledge gained and design ideas established were consolidated and built on through the development of design collections.

1.3.2.2 Evaluative Research
Langford and McDonagh (2003, p.5) highlight that focus groups can be used for various purposes including, the evaluation of existing or proposed designs and to establish frameworks for further research (ibid, p.7). John Chris Jones (1970) suggests that interviews can be used in a similar way. Questions Four and Five were addressed through a series of focus groups and interviews as this was considered the best way to mimic the way in which fabrics are presented to product designers and manufacturers in industry.
Chapter 1

Introduction

Work Conducted
An indication of the suitability of the fabrics for the high-end interiors market was gained through a series of interviews and focus groups with textile and interior product designers. The possibilities of producing the designs developed within the research on both small scale and mass production levels within an industrial context were considered by conducting a series of interviews with nonwoven manufacturers. Literature relating to design practice and theory was used to explore and articulate the results through qualitative analysis.

1.3.2.3 Analytical Framework
Within both the practical and evaluative research methods Victor Papanek's (1985) 'Function Complex Model' was used as an evaluative framework. The model defines six areas that represent different functional aspects of a designed object – Method, Association, Aesthetics, Need, Telesis and Use. The 'Aesthetic' and 'Method' aspects of the model formed the focus for the analysis in the practical work. These aspects were also used within the evaluative work alongside consideration of the 'Use' and 'Association' aspects. The Function Complex Model and definitions of each aspect, as applied in this research, are discussed further in Chapter Three.

1.4 Overview of Thesis Content
The thesis is presented within nine chapters and accompanying appendices.

1.4.1 Chapter Two: Literature Review
Chapter 2 outlines the contextual, historical and technical framework within which the research is situated. It also situates the research within the context of previous and current research in relation to nonwovens and design. The Chapter is presented in four parts. Part one further establishes the contextual framework for the work and develops discussion relating to industrial and craft approaches to design within textiles. The notion of craft is explored further, in particular the notion of 'craft knowledge' and its role within textile design for industry. Through this discussion, the relationship between craft and industry in regard to nonwovens is brought into question. The ideas presented in Part one are drawn upon to articulate and explore the results of the practical and evaluative research in Chapters 8 and 9. Part two, provides a brief overview of the origins and development of the nonwovens industry and current production, in doing so attention is drawn to the connections between craft processes and industrial manufacturing techniques. Part three outlines nonwoven production methods and technologies. In this section, traditional hand-based textile processes are mapped onto industrial nonwoven production methods, providing a starting point for the practical investigations. Part four reviews past and current research relating to nonwovens
and design (from a predominantly aesthetic perspective) and in doing so the direction of the practical research is brought into focus.

1.4.2 Chapter 3: Methodology
Chapter 3 sets out the methodological framework and methods employed within the research. It begins by discussing the nature of research within Art and Design with specific reference to textiles. The differences between quantitative and qualitative research within this context are defined and the framework of Naturalistic Inquiry as employed in this research is further established. The key research methods are described in detail including the notion of reflective practice, the use of focus groups and interviews within design research and the use of Victor Papanek’s Function Complex model as an analytical tool.

1.4.3 Chapter 4: Practical Research Stage 1
Chapter 4 describes and discusses the development of hand-based methods of nonwoven construction. Carding, chemical bonding and thermal bonding methods are explored. The methods used are based on the mapping process conducted through the literature review. The work is in many ways rudimentary but served to allow the researcher to gain hands-on understanding of nonwovens construction, the value of which is explored in the discussion of craft knowledge in Chapter 2. The Chapter describes the materials used, the fabric sampling equipment and procedures employed, and the reflective analysis that was made in connection with each investigation. Each fabric sample produced within this stage of the work was given a number. Where a specific fabric sample is referred to within the text its number is shown in brackets. The making details of each sample produced are presented in table format in the Appendices and key fabric samples are illustrated within the text. This system was also employed in Chapters 5, 6 and 7.

1.4.4 Chapter 5: Practical Research Stage 2
In order to begin to establish the opportunities and limitations of industrial nonwovens manufacture in relation to carding and thermal bonding, several periods of fabric sampling were conducted using pilot scale industrial equipment. The sampling process enabled the level of continuity between hand-based and industrial production to be established. It also enabled a suitable working environment and procedure to be established for use within the work outlined in the subsequent Chapters. Chapter 5 describes the materials used, the sampling equipment and procedures employed and the reflective analysis that was made in connection with each period of work.
1.4.5 Chapter 6: Practical Research Stage 3

The work outlined in Chapter 6 explored the potential to add further design value to the fabrics that had been produced by employing printing, embossing and laser processes. The work conducted included initial investigations into suitable adaptations of these processes for the nonwovens in question. Further investigations were conducted into the impact of different fabric construction parameters on the success of printing, embossing and laser process. This chapter forms the basis of the contribution to new knowledge presented within this thesis in regard to new fabrics. The opportunity, presented to the researcher, to manipulate the construction parameters of the nonwovens to optimise the quality of devoré printing and laser processes achieved, enabled a significant contribution to new knowledge to be made. The chapter provides a detailed study of the impact of fibre blend, needle-punching and thermal bonding parameters on the success of these processes. The materials used, the sampling equipment and procedures employed and the reflective analysis that was made in connection with each investigation are outlined.

1.4.6 Chapter 7: Practical Research Stage 4

Chapter 7 brings together the results and knowledge gained in Chapters 4, 5 and 6 through the development of design collections. A number of innovative and new nonwoven fabrics were achieved through the work discussed, which also form an important aspect of the contribution to knowledge made through the work. The Chapter outlines the approach to design taken by the researcher, the methods, materials and equipment employed and presents a reflective analysis of the making process and the fabrics produced. Within the analysis presented, the observations made that relate to the possibilities to produce the fabric designs on a small scale production level are included.

1.4.7 Chapter 8: Evaluative Research

Chapter 8 presents a period of evaluative work relating the aesthetic qualities of the fabrics produced and their suitability for high-end markets is presented. A series of focus groups with textile and product design professionals are discussed. To gain an indication of the feasibility of producing the fabrics developed within the context of commercial nonwoven manufacture, a series of interviews with nonwoven manufacturers are also discussed. The participant selection process, methods used and analysis made in connection with each set of focus groups and interviews is presented in the chapter.

1.4.8 Chapter 9: Conclusions and Further Work

Chapter 9 summarizes the work that was conducted and the research findings in relation to each of the research questions. This is presented within the wider context of the current
knowledge within the field and the relevant craft and design theory that was outlined in Chapter 2. In doing so, attention is drawn to the aspects of the work that contribute to new knowledge. Finally, areas for future work are identified.

1.5 Contribution to Knowledge
The areas in which the research findings contribute to new knowledge are summarized below:

- The establishment of a historical, technical and contextual framework in regard to nonwoven fabric design – the literature review presented in this thesis brought together historical, technical and contextual information in regard to nonwoven fabric design in a way that is not currently documented in present literature.

- The establishment of hand based methods of production that relate directly to industrial nonwovens technologies – hand-based methods of dry-laid web formation and chemical bonding methods were established to enable hands-on knowledge to be developed.

- New understanding of design possibilities at the web forming stage of nonwoven production when employing dry-laid methods has been developed – methods of incorporating a wide range of materials between fibre layers were established, key considerations to enable consistent production on a small scale production level were identified and the development of webs made from contrasting fibre layers for further processing was established.

- The adaptation of devoré printing and laser marking techniques for nonwovens made from a range of fibre types, specific constructions and with additional materials embedded within their structure – the methods of devoré and laser marking established enabled optimum fabric quality to be retained and contrasting surface effects to be achieved resulting in unique and new nonwoven fabric designs.

- The appeal of the nonwoven fabric designs within high-end markets assessed from a qualitative perspective – the qualitative approach taken within the research to gain external review on the fabrics produced enabled a number of key factors in regard to the value attributed to nonwovens within the high-end interiors market to be identified, further to this their suitability from an aesthetic perspective for this market was confirmed.

- Feasibility of producing the nonwoven designs developed within the present nonwovens industry assessed from a qualitative perspective – key issues that designers working with nonwoven technologies need to be aware of and sensitive to, to enable designs that are relevant for commercialisation to be developed were identified.
1.6 De-limitations
As highlighted within this introduction, the research is conducted from the standpoint of a
designer rather than that of a textile engineer, chemist or materials scientist. The work as
such does not provide scientific explanations of results presented, but rather provides
qualitative analysis from a design perspective. While the work takes every effort to be
technically and scientifically correct, it focuses on the creative and contextual aspects of the
research questions asked. In doing this, the research aims to work within the definition of the
designer's role as presented by Gianfranco Zacci (1995, p.9);

"At a certain point the seemingly divergent requirements of technical rationalism, emotional
content and sensory perception converge to complete a sphere. It is that sphere which
defines the true nature of aesthetics and the role of the designer in the product development
process. With this definition in mind, the designer must feel equally responsible for all
aspects of the total product. This does not mean that the designer becomes totally proficient
in all, or even any, of the technical specialities required to solve the physical problems. It
does not mean that the designer becomes a specialist in psychology or market research to
identify and integrate emotional values within a product design. It does mean however, that
the designer must be able to develop a clear understanding of where the natural balance
point it is..."

It is acknowledged that the results presented in this thesis are to an extent context and
researcher specific. As Chapter 9 demonstrates, however, specific aspects of the research
can be seen as significant contributions to knowledge that are relevant beyond the
researchers own design practice.

1.7 Chapter Summary
This chapter has outlined the research background and the research questions, provided an
overview of methodological approach taken within the research, given a chapter by chapter
summary of the thesis content; introduces the contribution to knowledge made through the
work and summarises key de-limitations of the research.
Chapter 2 Literature Review

2.1 Introduction
As outlined in the introduction, the purpose of this thesis is to identify the undeveloped opportunities to design nonwoven materials using a specific range of production processes and materials. The work aims to identify the potential and limitations of working as a designer-maker within this sphere through developing a body of innovative designs with the potential for manufacture on a number of production levels and for use within the mid to high end interiors market. This chapter presents the contextual, historical and technical framework within which the research is positioned and situated in regard to previous and current research in relation to nonwovens and design. The Chapter is presented in four parts.

Part one builds the contextual framework by developing the discussion relating to industrial and craft approaches to design within textiles. The notion of craft is explored further, in particular the notion of 'craft knowledge' and its role within textile design for industry. Through this discussion, the relationship between craft and industry in regard to nonwovens is brought into question. A number of the ideas presented in Part one will be in Chapters 8 and 9 to explore and articulate the results of the practical and evaluative research.

Part two provides a brief overview of the history and development of the nonwovens industry, in doing so attention is drawn to the connections between traditional craft processes and industrial manufacturing techniques.

Part three outlines nonwoven production methods and technologies. In this section, traditional hand-based textile processes are mapped onto industrial nonwoven production methods, providing a starting point for the practical investigations.

Part four reviews past and current research relating to nonwovens and design (from a predominantly aesthetic perspective); in doing so the direction of the practical research is brought into focus.
2.2 Part One: Contextual Framework

2.2.1 Introduction

Nonwoven textile manufacture takes place predominantly within the context of mass manufacture. Textile art, craft and design practitioners have also, however, utilised nonwoven fabrics and production technologies to produce unique textile artefacts. Kavanagh (2004) notes that product design is the result of informed and purposeful thinking in order to create something new that is appropriate and of value in a specific context. This part of the literature review chapter aims to clarify the context in which this research is situated and to develop a framework for understanding the meaning and value of its outcomes.

Three contexts in which textile production takes place will be further outlined; industrial design and production, craft production and ‘class production’. The way in which these production contexts interact and blur will be explored and the impact that this may have on developing innovative nonwovens suitable for the high-end market will be considered.

2.2.2. Textile Production Contexts

Textiles encompass a broad range of disciplines and activities. Each creates a different platform from which to consider questions, problems, inquiry and knowledge. Inquiry into textiles and the production of textiles take place within distinct contexts. Wilson (2001, p1) writes that textile making is an ‘ancient craft’ that has a history almost as old as mankind itself. She explains that before the industrial revolution textile manufacture took place within a domestic system that relied on hand-based processes and that the emergence of new machinery and the division of labour in the middle of the eighteenth century took textile making into an era of mass production (ibid). Both systems continue today and interact creating new modes of textile production and practice. As highlighted in the introductory chapter, nonwovens form a significant and growing sector of worldwide textile production.

2.2.2.1 Industrial Production

Industrial production is traditionally associated with mass manufacture. It is often associated with economic bulk production. Mass produced textiles are associated with mass markets and are often linked with what Wilson (2001, p. 9) describes as ‘mid volume’ or ‘low end market’ areas. It had been noted (Yair, 2001, p. 78) that, at this end of the market, fashion rather than quality plays a key role in the success of the product in the market place. High technology is used to enable high speed production and product turnaround to satisfy consumer demands for fashionable economic products.
Chapter 2  

Industrial Design

In terms of the designer's role within this context, Rees (1997, p. 117) considers the term 'industrial designer' misleading, as it implies that the designer 'designs for industry rather than for the consumers of the products of industry'. She suggests however, that designers 'do not ultimately design for producers but consumers'. This highlights that the need to consider the market in which the mass-produced object will be situated is imperative and places the focus on the qualities of the final object rather than the manufacturing limitations. Pye (1958, p. 55) highlighted, however, that 'when a thing is machine made or mass produced the machinery available will largely decide what its form and quality will be' and that more often than not the means will determine or at least modify the end'. This highlights the need for designers working in an industrial context to carefully consider the opportunities and limitations of the production technique being employed. Pye (1958, p. 55) suggested that rather than being an obstacle; this can be a stimulus to the designer's ingenuity. Rees' and Pye's insights point to the need to balance the requirements of the market in which one is working with the capabilities of the production techniques available.

As highlighted in the previous chapter, current nonwoven production is almost entirely industrial, producing fabrics for technical textile markets. The requirement is therefore to balance production capabilities with the market's need for the latest technical properties and performance capabilities. This research explores whether the requirements of the high-end interior market can be balanced with the production capabilities of the nonwovens area.

Textile Design for Industry

In traditional areas of textile manufacture such as woven and knitted textiles, industrial design and craft methods of textile manufacture are inextricably linked through design. It is common practice for a textile designer to produce designs in the form of fabric samples (or swatches) using hand-based or relatively low technology processes. Through the sampling process, a series of fabric designs is produced along with technical specifications which enable the design to be reproduced industrially. It must be noted, however, that computer software has been developed in most areas of textile manufacture enabling designs and specifications to be developed digitally. Designers working in this way produce fabrics for low, middle and high-end market sectors. Wilson notes (2001, p. 9), however, that the majority of fabrics and textile products currently produced within industry are sold in the middle volume or mass market area and in the lower or down market areas.

Is this approach applicable and relevant in the area of nonwovens?
2.2.2.2 Craft Production

Domestic systems of production are based on hand-based or low technology processes and skilled craftsmen/women. Having lost their focus as the main site for manufacture in industrialised countries, domestic or craft systems of textile production have sought new purposes. Dormer (1990) explained that, the continued practice of hand-based weaving, pottery, glass and woodwork processes and the artefacts produced became known as 'the crafts'. Greenhalgh (2002 p.1) suggests that the crafts have been persistent in retaining their significance, however, definitions of the 'crafts' and an understanding of their various facets and significance have been in constant debate within industrial societies of the twentieth century.

Craft Practice

The term 'craft' in its widest or traditional sense is used to describe a trade or skill. In industrialised society, however, the 'craftsperson's' role and context has changed. Dormer (1990, p.150), wrote that craft has changed from being a working class commercial occupation to a middle-class creative art-like activity. Within a contemporary context, craft incorporates activities or creative practices that embrace aspects and values of both Art and Design (Lees-Maffei and Sandino, 2004, p.207). Yair (2001, p.78), writes that the objects realised through craft practice often operate within a luxury goods market and derive their value from a sense of quality, tradition and customisation.

Craft practice within textiles informs design for industry but also functions as a distinct category of textile practice. Gale and Kaur (2002, p.63) write that textile craft practice is 'commonly perceived as multi-media, exploring the inherent qualities of different textile materials' and that a 'craft approach to textiles is very much process-led; the actual pursuit of making by hand is of paramount importance'. The nature of hand work enables personal interaction with the making process and an instinctive response to materials which is central to the design process within craft practice. Textile products produced through craft practice usually function in niche, high-end market areas due to their exclusivity.

Craft Aesthetic

Dormer perceived (1990, p.160-169) an aspect of the value of craft lies in the 'textures and forms of a lumpen, organic, richly textured aesthetic' as apposed to a smooth 'machine' look and the imperfect being perfect. This is not always applicable or desirable, however, within the context of contemporary design. Rees (1997, p.122–123) suggests a more subtle interpretation of what a craft aesthetic might be, writing 'that the relationship between craft process and product is likely to be, if not quite transparent then relatively, accessible to most of us'. She suggests that industrial design conceals the making process but that craft objects
enable a connection between the making process and consumer. Rees’ (1997, p.117) discussion implies that craft objects subsequently derive high value from association with a creative individual.

Is it possible to imbue nonwovens with a sense of ‘craft’ and subsequent consumer value required within high-end textile markets?

Design within Craft Production

In terms of the designer's role within craft production, theorists suggest that the process of designing and making are often completely integrated. Pye (1958, p.57) wrote that 'the characteristic quality of hand-work which has always been prized is not accidental but designed'. He went on to say that these prized qualities are 'the result of deliberate intentions about the shape of very small details and qualities of surfaces' and that these details and qualities are realised within the making process rather than being 'conveyed in drawings or words'. In relation to this, Rees (1997, p.118) notes that 'innovation is maker - led... reflecting personal choice, self-expression or experimentation with techniques and materials'. She suggests that although the market in which the object will operate impacts upon its realisation, it is ultimately the making process that dictates.

An approach to the production of designed objects that takes on board these ideas is referred to in this research as a 'craft approach' to design. This contrasts the approach to industrial design as discussed by Rees (1997, p.117) in which consumer and market needs and desire drive development. The work aims to explore whether a craft approach is relevant and viable within the area of nonwovens.

Craft Knowledge

The knowledge produced through the personal interaction with materials and process, that a craft approach to design requires, has been described as 'craft knowledge'. Dormer (1994, p.11 and 1997, p.140) described craft knowledge as practical knowledge that requires both technical knowledge and 'know'. Yair (2001, p.60 and p.289) notes it is often discussed in terms of an understanding of or feel for materials and describes the thought processes that produce craft knowledge as 'context specific and non-rational, drawing on practical knowledge gained through experience and stabilized in the bodily domain'. Yair (2001, p.289) goes on to explain that within western culture craft practice is 'valued primarily for the object produced, rather than the knowledge embodied in it'.

Dormer (1994, p.14), notes that 'Tacit Knowledge' is the preferred phrase for craft knowledge amongst academics. He notes that tacit knowledge is gained through experience and can not
easily be articulated in words or mathematically described. Dormer (1994, p.11) highlights that notions of local knowledge, as opposed to general knowledge, relate to craft knowledge.

Yair (2001, p. 62-61) draws on Johnson (1997), McCullough (1996) and Pye (1968) to summarize that crafts knowledge enables the maker to predict how an object will respond to manipulation even in situations outside the immediate working context and provides knowledge relating to the medium's affordances and constraints. The application of this knowledge, as Pye (1968, p.47) notes relies on judgment and contextual awareness.

This research asks whether craft knowledge is relevant within nonwovens design? How would it be applied? Would a craft approach to nonwoven design and production result in the realization of high value nonwovens with 'prized qualities'? Is craft knowledge valuable to the nonwovens industry?

2.2.2.3 Designer Maker Practice and Class Production

Although it is possible to theoretically identify certain approaches to textile production, in relation to actual practice Rees (1997, p. 134-135) writes that explaining industrial design and craft through a dichotomy of separating values is no longer relevant. She suggests that, such dichotomies - machine-made vs. hand-made, mass market vs. luxury market, urban vs. rural, male vs. female, innovative vs. traditional and sophisticated vs. vernacular – are perceived as 'porous boundaries' which contemporary craft practitioners and industrial designers either exploit or resist. The emergence in recent years of what had been termed Designer-Maker practice demonstrates a porous approach to the production of artefacts.

Since the 1980's the notion of 'designer-maker' practice has become established within all areas of craft and design (Taylor, 2001). The term designer-maker is applicable to a range of design disciplines including Textiles. Designer-maker practice is a continuum between industrial design practice and craft practice and involves the interaction of designing, making and manufacturing in a small business setting. Designer-makers usually produce batches of products and, whilst a craft approach to design often informs the development of prototypes, the products themselves are often subcontracted to industrial manufacturers or taken on by major retailers. This differs from craft practice in that full control is not maintained by the maker but rather negotiated with industry. Further to this, Greenhalgh (2002, p.3) notes that craft practitioners have expanded to become industry-scale producers and are employed by manufacturers to produce prototype products for batch production. Like craft products, designer-maker products function within niche, high-end markets and, as Gale and Kaur (2002, p.50) note, they often demonstrate the craft origins of their design which contributes to their value.
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In regard to textile design and manufacture, Jack Lenor Larsen (1989, p.39) proposes another mode of textile design practice and manufacture that essentially considers a continuum between craft and industrial production. He notes a danger in polarising textile making as either the pursuit of 'one-off' or 'mass produced' goods and has developed a philosophy of production that integrates the two. He terms this philosophy 'class production' and states that it revolves around the production of luxury fabrics, in small runs that are fuelled by an innovative and creative approach to manufacture. The fabrics produced function in high-end market areas. Larsen notes that the success of this approach lies in design development being central to production and marketing rather than subordinated to it.

This research pursues the idea and potential of such modes of design practice within the area of nonwovens manufacturing. Is it possible to integrate craft and industrial approaches to manufacturing within the sphere of nonwovens?

2.2.3 Craft and Industry

Both Greenhalgh (2002, p.3) and Rees (1997, p.134–135) suggest that the dissolving of boundaries between craft, industrial design and art has been facilitated by high-technology. Greenhalgh adds that the key to success within this integrated context is the willingness to collaborate. The discussion below looks at the relationship between craft and industry in relation to textile manufacture, highlighting perspectives on current role of craft in industry, the use of new technologies and collaborative processes. The aim is to highlight and identify potential considerations in approaching nonwovens through an integrated approach to design that considers both industrial and craft perspectives.

2.2.3.1 Crafts Role in Industry  

Tanya Harrod (1999, p.119), emphasizes the importance of craft practice to the development of industrial production. Harrod (ibid) refers to Walter Gropius' prediction in 1928 that 'in the future their (the crafts) field will be research for industrial production and in speculative experiments in laboratory – workshops where the preparatory work of evolving and perfecting new-type forms will be done'. Woven textile designer, Sophie Roet (2003, p.1), describes the contemporary fulfilment of this prediction explaining two ways of developing textiles for industry. The first, she explains involves 'not considering the sort of limits industry can have' in order 'to inspire the industry' and to allow manufacturers to interpret ideas in a way that is 'suitable for their industry'. The second, Roet (ibid p.3) explains, is a mode of design that is intended 'for industry' but that pushes its limits. Roet (ibid, p.6) describes the textile designer's role in industry as 'fusing traditions and contemporary developments'.

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Do such modes of working exist within the nonwovens industry and are they viable in regard to the development of fabrics for the interior decorators market?

2.2.3.2 Technology and Textiles

Over the last two decades, there have been rapid technological developments within all spheres of the textile industry. In relation to textile craft and design practice during this time, Lesley Millar (2002, p.4) writes that 'textiles are often seen as being at the interface of science, art, technology, architecture and design...and have been the site for creating newness'. She notes that a number of exhibitions, symposiums and books have documented the innovations realised during this period. It is widely acknowledged that the fusion of traditional skills and new technology has been a crucial element of this development.

The apparent ease with which textile practitioners use new materials and the continuity of process found between craft and industrial production methods were suggested by Dormer (1997, p.168) as reasons for much of the innovation achieved. Dormer (ibid) wrote that 'of the craft areas, textiles, especially woven cloth, is most at ease with the demands of technology and design of contemporary western culture'. He noted that the reasons for this lie in the continuity that exists between the craft and industrial production in this area. This fluidity of practice, he suggested, lies in the conceptual and technical basis of woven cloth, which enables samples produced on a hand-based level to be easily translated into industrial production 'without fuss'.

This research explores whether such fluidity is possible between hand-based and industrial nonwoven technologies.

2.2.3.3 Collaboration

The value of craft/industry collaborations has been acknowledged and encouraged by a number of initiatives over a number of years. An initiative called Texstyles, which was set up by the crafts council in 1984, set out to establish collaborations between textile designer makers, manufacturers and retailers. Jan Cummings (1984) explains the emphasis of the project was the development of innovative textile work suitable for small scale or batch production runs. The underlying aims were to promote British design through focusing on the development of specialised high-end fabrics. More recently, an initiative called 'hi-tec lo-tec' teamed selected craft practitioners with a broad range of industrial manufacturers. The initiative aimed to expose craft practitioners to the creative opportunities afforded by industrial technologies and in turn promote the value of craft practice in developing innovation within industry (O'Mahoney, 2002). Research into craft/industry collaboration across the crafts has provided insights into how such collaborations best function. Yair's (2001) case study
research into the value of craft/industry collaborations highlights key areas of consideration in developing successful collaborations. They include; mutual benefit, contextual-fit, sensitivity to industrial manufacture and shared languages. Each of these is outlined here.

**Mutual benefit**

The physical results of craft/industry collaborations such as those undertaken in the ‘hi-tec lo-tec’ project are often one-off artefacts. Although these artefacts contain valuable information relating to innovative uses for industrial technologies, the development of commercially viable products through the application of such innovations are not always suggested or explored. This creates a situation in which the industrial manufacture can not always see a clear benefit from the collaboration. Yair (2001) highlights that for collaborations to be successful, the projects that are undertaken need to be beneficial to both the craft partner and the industrial partner.

**Contextual Fit**

Yair (2001, p 83) refers to the concept of ‘contextual fit’ as articulated by Cooper (1996), who highlights contextual fit as a requirement for successful collaboration. Yair notes that Cooper’s study of ‘contextual fit’ (or product synergy) is concerned with the potential success of the product in its market place. Yair (2001, p281) goes on to explain that the ability of a crafts person to produce ideas and products that are well suited to the company’s production capabilities and market opportunities is perceived as essential to successful collaborations. In order to understand production capabilities. Yair (2001 p, 83 -84) draws on Jevnaker (1998) and Ingols (1996) to explain that context specific information relating to available skills, technological expertise and management systems is required to achieve contextual fit. She also highlights, however, that such information is difficult to attain as it is often tacit. Further to this it is noted by Yair (2002,p. 84) that Lawson’s (1990), identification that conventional industrial design processes can often inhibit the gathering of such information suggests that a craft approach may unearth it enabling greater contextual fit to be achieved and consequently more successful collaboration.

Literature on the nonwovens industry, suggests that the expansion of nonwovens market areas is a serious consideration (Nonwovens Network, 2002 and O'Mahoney, 2001). Most nonwovens companies, however, move within the sphere of technical textiles and mass-produced commodity products. This research questions the impact that notions of contextual fit might have on the development of high-quality nonwoven fabrics at different production levels. It also questions whether, by considering both craft and industrial perspectives on manufacture, it is possible to develop designs that, as Yair (2001, p.281) suggests, 'stretch
existing capabilities to an acceptable degree' thus generating new knowledge and suggesting new applications for existing technologies.

**Sensitivity to Industrial Manufacture**

Although the aim to stretch manufacturing capabilities is required in order to achieve new knowledge and innovation, accounts of collaborations between individual makers and industrial manufacturers point to the need for a deliberate sensitivity to such capabilities on behalf of the maker. Product designer Robin Levien (1998, p.19-22) highlights a number of difficulties in relation to this by reflecting on collaborations between ceramicists Susan Pryke and Ikea and Lucie Rie and Wedgewood. Levien (ibid, p.21) explains that Pryke was commissioned to develop a series of domestic forms for the '365+ range'. Levien (ibid) notes that Pryke worked freely to refine her concepts before considering the limitations of the production processes but that much of this effort was wasted because the work proposed proved too expensive for production. Similarly, Levien (ibid, p.20) notes that, the free reign given to Rie at the onset of the design process resulted in products that required skilled and slow methods of production that proved too expensive for larger scale production and, further, that the results did not look as expensive as the process might have suggested.

**Shared Language**

Dormers (1997, p.168) discussion of 'fluidity of practice' between hand produced and industrially produced woven textiles, emphasized the positive results of a shared technical and conceptual language between spheres. As Dormer (ibid) explained, this language is rooted in the continuity of processes which are based on basic principles of construction. This language, Yair (2001, p.280) suggests is communicated verbally and visually but highlights the requirement of a further mode of communication for successful work between individual makers and industrial manufacturers. She describes this mode of communication is described as a 'specialist, verbal-visual-bodily language'. This language, Yair (2001, p.164 and 281) explains, 'employs a concurrent process of articulation and demonstration' and enables ideas to be 'conveyed directly through the manipulation of materials and objects' (ibid, p.). She suggests that the result of such communication is the assimilation of knowledge between practitioner and production staff.

With regard to the development of innovative textiles using new technologies, Kavanagh (2004, p.3). considers that the ability of the designer to communicate with technologists is often a pivotal point that can either make or break innovation. To avoid breakdowns in communication, he emphasizes that designers must be ‘willing to learn the underlying principles of the technology they are working with and develop a competence in using the appropriate terminology’ (ibid, p.4). This research aims to identify the underlying principles of
nonwoven production that enable fluid translation of ideas between manufacturing contexts and to assimilate knowledge in regard to the design possibilities of certain production methods through pursuing experiential understanding of the relevant materials and processes.

2.3 Part Two: Nonwoven Origins and Current Production

2.3.1 Introduction
This part of the literature review provides a brief overview of the history and development of the nonwovens industry, in doing so attention is drawn to the connections between craft processes and industrial manufacturing techniques.

2.3.2 Craft Roots
Jirsak and Wadsworth (1999, p. 3) write that Nonwoven fabrics originate in what was probably the earliest form of textile production - the processing of animal hair and vegetable fibres by mechanical action using water, heat and chemicals. Similarly, they note, vegetable fibres were used to produce matted straw, the resulting materials were used as clothing, bedding and building materials.

The term ‘nonwoven’ implies something that is simply ‘not woven’ but there are a number of precise definitions that give specific details as to what can and cannot be described as a nonwoven. These definitions and the term itself have been in constant debate throughout the evolution of the nonwovens industry. Jirask and Wadsworth (1999, p. 7) highlight the fact that constant technological developments create new processes and products that place precise definitions in a continual state of change. The International Nonwovens and Disposables Association (INDA) definition is, however, the most summative:

‘Nonwoven: A sheet, web or, batt of natural and/or man-made fibres or filaments, excluding paper, that have not been converted into yarns, and that are bonded to each other by any of several means’ (Batra et al, 1999 p. vii).

The processes and materials used to make nonwovens and the qualities of the end products themselves link them to the chemical, plastic, felt and papermaking industries. Although there are similarities, the various elements of production and materials used to make nonwovens create a unique and specific industry. The various definitions of what constitutes a nonwoven highlight in detail the differences between nonwovens and other materials such as felt and paper. In doing so, however, an inextricable link is emphasized.
Most definitions of nonwovens technically exclude woollen felts and paper. For example the current British Standards (BSI, 1992) definition states that nonwovens:

‘...exclude paper and products which are...felted by wet milling whether or not additionally needle’d’.

The notes that accompany this definition go into detail as to what constitutes a paper and what can or cannot be considered as a felt. Textiles literature, however, often refers to felt as a nonwoven fabric (Burkett, 1979, p. 7) which, alongside the physical similarities of felt and nonwovens, makes an explicit link between the two. The similarities between the hand-based and industrial processes used to make felt and those used to make nonwovens also link them clearly. The process of felting can be described in three or four main stages; the preparation of animal fibre, the formation and layering of fibre batts (or webs) and the consolidation or bonding of these fibre layers through mechanical work and chemical action. The bonding of wool fibres relies on the chemical and structural properties of wool fibre under the application of heat, pressure and moisture. Various finishing processes can be considered as a fourth stage in production. Similarly, the process of making a nonwoven can be described in three or four main stages:

- Fibre preparation
- Web formation
- Web bonding or consolidation
- Fabric Finishing (optional)

In summary, both processes involve the construction and consolidation of flat sheets of fibre.

The intention in highlighting such similarities is not to form a comparative study but rather to draw and create links between industrial processes and their craft based origins. In doing so it is hoped that a link can be formed enabling ideas relating to design and aesthetics to be explored within what is a predominantly technically driven industry. Having begun to explore areas of crossover between nonwoven and felt from a process perspective, felt is explored briefly here in terms of its original significance as both a functional and decorative material. The intention in doing this is to begin to explore the cultural and decorative significance within the craft roots of nonwovens and highlight their potential as ‘designed’ materials.

### 2.3.3 Felt—Cultural and Decorative Significance

Although the origins of felt are unknown, according to Burkett (1979, p.7 and p.18) the earliest archaeological examples found in Central Asia enable its production to be dated to c. 600 B.C. and literary references to the use of felt in China enable its use to be dated back to 230
B.C. Such archaeological and literary evidence suggests that woollen felt was originally used for both functional and decorative applications. Burkett (1979, p.10) and Smith and Walker (1995, p.5) document that historical finds include a wide range of functional felted objects including rugs, cushions, socks, tomb covers, vessel supports, men's outer shirts and women's hair accessories as well as decorative items including saddle covers, masks and mane covers for horses. As can be seen in contemporary felted products, Smith and Walker (1995, p.5) note that many of these felt objects were heavily patterned pointing to their decorative as well as functional properties. Burkett (1979, p.25) lists decorative aspects including floral, geometric, and figurative elements which were achieved using a range of techniques incorporated into the felting process. She notes that alongside appliqué, cutting and painting techniques were used on completion of the felting process to incorporate decorative properties.

Historical literature provides further evidence for the varied use of felt throughout history highlighting both its technical and aesthetic importance. Laufer (1930 in Burkett 1979, p.1) records a quote from 1845 that referred to a felt as having 'resistance comparable to armour' being 'impenetrable by firearms or sword'. Burkett (1979, p.7) suggests that in its earliest use felt was preferred above woven textiles for its protective properties. In terms of aesthetics, as well as traditionally holding decorative importance, literature suggests that felt has significant cultural meaning. Burkett (1979, p.21) writes that heavy reliance by nomadic peoples on felt for clothing and domestic purposes led to areas of Central Asia being described by the Chinese during the fourth century as 'land of felt'. Within this area felt was thought to hold magical as well as ritualistic properties. Laufer (1930, p.15 in Burkett 1979 p.21) describes that it was used to make cut out figures that were thought to bring prosperity and protection.

From these early beginnings felt has continued to be a common product in both eastern and western societies. Smith and Walker (Smith and Walker, 1995 p.6) suggest that due to industrial developments hand felting focuses on fashion and decoration rather than utility. Do contemporary nonwovens function in products where decorative rather utilitarian properties are the focus?

2.3.4 Needle-felt and the Development of Nonwoven Technologies

From hand based origins, industrial manufacture of felt developed. The same principles of construction remained but the hand was replaced with automated machinery capable of mass manufacture. Industrial felts are predominantly used in functional applications as varied as billiard table tops, piano key components, machinery covers and display boards (design applications as above). As outlined above, industrial felts have many of the same properties and qualities as hand made felt in terms of function and aesthetic. The main difference is the weight, thickness and uniformity of surface that can be achieved in industrial manufacture.
The emergence of nonwoven production as a specific and unique form of fabric making, separate to felting (and paper making), lay almost purely in industrial development. The first move towards nonwoven manufacture was the development of what is known as 'needle punching' or 'needle felting'.

Needle punching is a process by which fibre layers are entangled mechanically through the vertical 'punching' movement of barbed needles within the fibre web. In an overview of needle felt technology, Johann Philipp Dilo (2004, p.18), writes that the beginnings of the needle felt industry lie in the end of the nineteenth century and were realised mechanically by the English company Bywater. This new technology made it possible to process recycled materials such as regenerated clothing waste at high speeds. According to Masenaux (2003, p.4), early developments were also influenced by the raw materials restrictions that were put into place in Eastern Europe following the Second World War and the consequential need to recycle fibrous waste. The economic advantages of production prompted applications for the fabrics produced in products such as carpet backings and mattress felts. This, writes Dilo (2004, p.18), led to a 'shadowy existence' of the fabrics produced and a perception of them as the 'poor relation' of high quality woven fabrics'. He suggests this perception has been remarkably lasting. A focus by the industry on niche properties as well as cheap production has, to some extent changed this, but, in terms of technical rather than aesthetic products.

From here, a 'rapid development of new unconventional techniques in textile production' is reported (Kcrma, 1971, p.13), leading to the beginning of a recognisable industry in the 1960s (Massenaux, 2003, p.4). Massenaux suggests that during these initial stages over two hundred patents recognising technological developments, machines and products relating to what was perceived as unconventional textile production were registered. The term 'nonwoven' as an overarching description for these developments was first used in relation to commercially produced adhesive bonded fibre webs (ibid). Kcrma (1971, p.13 and p.15) notes that in the initial assessment of this new group of products, inconsistencies were noted as well as objections to the negative sense of the term 'nonwoven'.

Needle-felts, as a product, were one such topic of dispute. In Belgium and Germany needle-felts were classified as woollen felts even though most of the products contained synthetic fibres rather than wool. The Textile Institute (Tubbs et al, 1991, p.113) classifies a needlefelt, as a felt rather than a nonwoven. It notes, as does the British Standards (BSI, 1992), definition of nonwovens that the term nonwoven excludes any fabric that is 'felted by wet milling whether additionally needled or not' (Tubbs et al, 1991, p. 211) and highlights the danger of limiting the needling process to felted products and that it is in fact a bonding method of nonwovens in it's own right (ibid, p.212).
Kcrma (1971 p.15) writes that dispute relating to the negative sense of the term 'nonwoven' has hindered the industry since its inception. He notes that at this early stage, other terms such as 'bonded fabrics' or 'fibre fabrics' have been suggested as alternatives that are more suitable, but that they have only been taken up where literal translations cause less confusion. One example is the German term Vliesstoffe, which translates as 'textiles made of fibre webs' (Massenaux, 2003, p.1). The term 'nonwoven fabrics' became generally accepted and has yet to be superseded as the common term for this group of textiles created by what were perceived as unconventional methods at that time (Kcrma, 1971, p.15).

2.3.5 Nonwoven Fabrics, Applications and Industry Developments

In what was one of the first manuals or 'treatise' on nonwovens, Kcrma (1971, p.9) deals with the topic of nonwovens 'from the viewpoint of their structure and...the main factors that qualify, effect or regulate it thus influencing the properties of nonwovens and the scope of their application'. This inextricable link between structure and end use along with the desire to retain the economic advantages of high speed and low cost production has characterised developments within the field. The utilitarian beginnings of the industry have been retained and have formed the focus for development. The Association of the Nonwoven Fabrics Industry's (INDA) (Batra et al, 1999, p.iii) introduction to nonwoven fabrics states that 'the success nonwoven products have achieved lies in the ability of the industry's technologies to produce materials with specifically engineered performance properties and economic advantages' and that 'nonwovens satisfy many of the ever-increasing needs of industrial society'. The European Disposables and Nonwovens Association (EDNA 2006) list over forty engineer-able properties for nonwovens and over 100 product applications. Engineered properties of nonwovens include; abrasion resistance, breath-ability, rot and mildew resistance, sterilise-able, tear resistance, weld-able, skin sensitivity and conductivity.

In the early stages of development, nonwovens were engineered as economic replacements for utilitarian (or durable) products where traditional textiles were used. Products included carpet backings, interlinings for clothing and shoe components. Alongside this, nonwovens have played a key role in the development of disposable products such as nappies and personal and domestic hygiene products. Latterly nonwovens have been engineered for specific technical applications such as medical textiles including contamination control garments and wound dressings, agricultural products including weed control fabrics and crop covers, products used for soil stabilisation and tennis courts within the area of geo-textiles and as mouldable components within automotive applications. As part of the initial research for this thesis, a range of nonwoven fabrics used in such applications were collated in order to gain a broad picture of the type of fabrics being manufactured, the materials and process used and their properties and qualities from an aesthetic and design perspective. The following paragraphs and images describe a small selection of the samples collated.
2.3.5.1 Collated Samples

Figures 1 - 9 show examples of some of the fabrics collated. They illustrate a range of visual properties, weights, densities and surface qualities. Figure 1 shows a fabric called 'Technodens' by a company called BBA fibre web. It has a similar appearance to felt but a much more synthetic handle. It is similar in quality to wadding for upholstery and has a slightly 3D grid structure on its surface. The fabric was produced using polyester fibre and a thermal bonding process. Similarly, the sample shown in Figure 5 was made using a thermoplastic fibre. This fabric produced by Cantensa can be moulded after exposure to heat. The resulting fabric is used as internal side and door panels in cars. It has an extremely inflexible and hard handle. The side shown in the image has a grainy, fibrous appearance and flat compressed surface. The reverse side has a much softer felt like surface that may be visible within the cars interior. Both fabrics have a very industrial and hard-edged aesthetic.

Figure 1: 'Technodens' by BBA

Figure 2: 'Base 1' by BBA

Figure 3: 'Linotec' by BBA

Figure 4: 'Barkweave' by Cambrelle

Figure 5: 'Catflax' by Cantensa

Figure 6: 'Colback' by Colbond
Figures 2 and 3 show fabrics that have been made using what is called a spunbonding process. The images illustrate the range of densities and weights achievable using the same construction process. Figure 2, 'Base 1' weighs fifteen grams per metre square and has gossamer-like properties. It is sheer enough to allow the individual fibres that make up the fabric to be visible creating an ethereal, delicate and web-like appearance. It has a soft, almost silky handle. Figure 2, Linotec is a heavier and denser fabric weighing sixty-five grams per metre square. It has a dimpled surface created through a calendaring process. It is reminiscent of paper but does not hold a sharp fold, it is similar to fabric but with no drape and is evocative of a soft plastic.

The samples shown in Figure 4 also have an embossed quality created through the calendaring process. The surface made from bi-component fibres mimics woven cloth. The fabric is made by Cambrelle, a Dupont company, and is produced in a wide range of colours for sports shoe lining. They also create fabrics that mimic natural surfaces and stitched structures. The fabrics are visually interesting with a quality that sits between paper felt and plastic and is predominantly synthetic in terms of handle and colour. Figure 7 has a similar quality and has a visually intriguing patterned surface created by embossing. The fabric is used as cleaning cloth. Made from what appears to be layers of plastic film between fibre webs, the material is apparently durable enough to clean grease, solvents, glue and oil.

The samples shown in figures seven and eight show the visual impact of reinforcing structures within the nonwoven web. Figure 7 shows a composite of needle-punched polypropylene, a three-dimensional plastic grid-like structure. The fabric produced as a geotextile by Geofabrics is used in drainage systems in soil embankments. It has a very coarse and cumbersome handle but the combination of fibre web and linear grid is interesting in that there is a recognisable structure. Similarly, the fabric shown in Figure 9 is an example of a fibre web reinforced through the stitchbonding process. Again, the integration of a graphic structure into the organic structure of the fibre web is visually interesting. The mixed
fibres and polyester stitching thread used in this fabric give it quite a soft felt like quality but with a coarser synthetic surface.

The sample shown in Figure 6 is perhaps one of the most recognisable nonwoven fabrics. Colback™ by Colband Nonwovens, predominantly used as carpet backing, is one of the first nonwovens to be used in decorative applications. It is made using a process similar to spunbonding from extruded polyester bi-component fibres. Its whimsical, web-like, glossy and gossamer appearance and its stiff strong handle have led to a number of decorative applications including gift and flower wrap.

As the samples illustrate, and as highlighted by INDA’s introduction to nonwovens, by using different nonwoven production methods it is possible to create fabrics that are flat or lofty, absorbent or non-absorbent using separate fibres, molten plastics or plastic films. Batra et al explain (1999, p.iv) that a range of weights and densities can be achieved resulting in fabrics that are gossamer like and paper thin to fabrics that are bulky and have the quality of thick padding or that mimic the appearance and technical properties of woven fabrics. Although a range of physical properties are possible, many of these fabrics are produced at many hundreds of feet per minute (ibid) with economy in mind and so reflect their industrial origins and technical destinations.

Common dissatisfactions with nonwovens have been their poor drape, low recovery properties, stiff handle and sometimes inferior strength when compared with traditional textile structures. However many of these problems are being overcome through current research. One such example is the development of an elastic fabric by BBA Advanced Design Concepts. The fabric reportedly represents the ‘first truly elastic spunbond nonwoven, balancing elastic performance and aesthetically pleasing touch and improved cost/performance’ (Abed, 2005). In their promotional literature, the makers of the fabric highlight the fact that the fabric will offer new product possibilities that have not yet been economically viable in terms of elastic materials in the personal-hygiene, medical and apparel industries. Semi–disposable sports wear has been suggested as a potential end use for these fabrics (Abed, 2005). On handling, the fabric has a strange spongy, soft handle and similar visual qualities associated with fibre webs. Although aesthetics are considered it seems that it is still from a very functional and technical perspective. Such developments are, however, opening up new possibilities in terms of alternative applications.
2.4 Part Three: Nonwoven Technologies

2.4.1 Introduction
This section outlines and summarises industrial nonwoven technologies. It begins by re-capping definitions of nonwovens and production classification. The main nonwoven production processes and technologies are then outlined. Although not all of the processes described are explored within the practical research, it has seemed relevant to include them for clarification as they are referred to in later parts of the text. Hand-based fabric construction techniques that are similar to industrial nonwoven processes are highlighted throughout. This ‘mapping’ process is intended to draw attention to links between craft and industrial fabric production techniques and to provide a starting point for practical exploration, experimentation and design considerations. As Dormer (1994, p.10) suggested, theoretical knowledge can be described as a springboard for action and provides insights into how fields of action work. As such, this chapter provided the theoretical framework for the practical work.

2.4.2 Definitions
To re-cap, Nonwovens are described in the Textile Institutes Textile Terms and Definitions (Tubbs et al, 1991, p.211) as those fabrics that are made directly from fibre rather than yarn. They are made from continuous fibre filaments or fibre webs that are strengthened through various bonding techniques. As noted previously, there are a number of precise definitions for nonwovens. The discrepancies between these definitions leave a number of grey areas of classification, usually at the boundaries between nonwovens and other materials. Some nonwovens contain wood pulp creating an unclear boundary with paper. Others contain reinforcing yarns or fabrics that challenge the general perception of nonwovens as being predominantly fibre based and terms such as ‘needlefelt’ link nonwovens with felt. As EDANA (2006 (2)) notes although nonwovens have emerged from the textile, paper, plastic and leather industries, they have evolved into a ‘separate, innovative and completely flexible industry’. For the purpose of this research, the British Standards (BSI, 1992) definition, as quoted in the introductory chapter, will be used.

2.4.3 Classification by Production Methods
As the British Standards definition suggests a number of manufacturing technologies exist within nonwoven production. Nonwovens are, therefore, often classified in terms of the methods used to make them.
Nonwoven production can be described in three or four main stages:

- fibre preparation
- web forming
- web bonding
- fabric finishing

Some discussions include fibre preparation as integral to web-forming therefore focussing on only three stages of production (EDANA 2006 (2) and Batra et al, 1999). Fibre preparation involves the cleaning, opening and blending of fibres (processes that are associated with spinning technologies). Finishing techniques used in nonwoven production are often similar to those used in traditional textile production. They are sometimes integral to the nonwoven manufacturing line or implemented as a separate stage of production.

Web formation and Web bonding technologies will be discussed in this chapter and finishing techniques will be briefly outlined. Fibre preparation is not discussed in detail as it is treated as an integral aspect of web formation.

Figure 10 shows a classification of nonwoven methods of web forming and web bonding. As shown, web forming methods are usually classified within three distinct categories and a further three categories are used to classify web bonding methods. The main technologies used within each are outlined.
Nonwoven Fabric Production

Fibre Forming

Polymer-Laid

Spun-laid
Melt-Blown
Combined

Thermal

Calendering
Through-air

Mechanical

Needle-punching
Hydroentanglement/Spunlacing

Dry-laid

Carding
Airlaying
Combined

Web Bonding

Needle-punching
Hydroentanglement/Spunlacing

Mechanical

Coating
Spraying
Printing
Impregnating

Chemical

Calendaring
Through-air (oven)
Ultrasonic

Thermal

Figure 10: Nonwoven Production Methods: Web Forming and Web Bonding
(Based on the classification system developed at the University of Bolton).
2.4.4 Web Formation

The first stage in nonwoven manufacture is the arrangement of fibres into a loosely held together sheet structure called a web (EDANA 2006 (2) and Batra et al, 1999, p. 46). The fibres can be in the form of short lengths called staples or continuous lengths that have been extruded from molten polymer granules called filaments (Batra et al, 1999, p.46). As Figure 10 shows, three general methods are used in the web forming process: dry-laid, wet-laid and polymer/spun-laid. Jirsak and Wadsworth (1999, p.51) explain that these methods differ from each other in terms of productivity, fibre orientation and the properties of the web they produce.

2.4.4.1 Dry-laid

There are two main methods of dry-laid web formation: carding and air-laying. These technologies are also used in combination in mechanical - aerodynamic methods.

Carding and Cross-lapping

Carding is a mechanical process that starts with the opening and blending of raw fibres. Following this process, the fibres are passed through a series of rotating drums covered in fine wires and teeth as shown in Figures 11 and 12. Each of these drums performs a different role in the process but essentially comb the fibre into parallel arrangements although some systems have mechanisms that enable fibres to be randomly arranged (Jirsak and Wadsworth, 1999, p.61). The arranged fibres form the web. The web is then layered using various mechanisms to create either parallel-laid or cross-laid web constructions of different weights. In parallel-laid webs, the fibres are orientated in a lengthwise manner, usually in the direction of the machine, and is described as unidirectional or anisotropic (Schaffler, 2003, p. 160). Such webs have higher tensile strength in the direction of the machine than the direction across the machine (cross-directional). Cross-laid mechanisms layer webs on top of each other at angles as shown in Figure 13. Webs produced in this way have increased cross-directional strength. The greater the number of layers the greater the weight of the resulting nonwoven. Both synthetic and natural fibres, usually up to 150mm in length, can be used in the carding process (Batra et al, 1999, p.46).
Figure 11: Single Cylinder Card (Jirsak and Wadsworth, 1999, p. 53).

Figure 12: Close up of Carding Rollers (Jirsak and Wadsworth, 1999, p. 53).
Industrial carding technology as described above can be dated back to 1748 and was originally used for preparing raw fibres for spinning and subsequent yarn production (Kittelmann and Beenhardt, 2003, p. 148). The concept of carding, however, goes back further than the industrialised technology. Carding is a major aspect of hand-based spinning and felting processes.

In hand-based felt production carding is used to prepare fibres for spinning and in felting is used to make woollen ‘batts’ (or webs) for wet milling. On a hand-based level, carding is achieved through the use of hand cards or drum cards. Hand cards, as shown in Figure 14, are made up of rectangular boards with wire teeth across them. Small amounts of fibre are spread over the surface of a card and another is drawn across its surface. The cards are pulled in opposition arranging the fibres in a parallel fashion. Drum carding enables greater quantities of fibre to be carded. As shown in Figure 15, a drum card is essentially a much smaller hand-based version of an industrial card. There are fewer drums (usually two) and they are operated by hand. The fibre is fed into the mechanism, and where the wire covered drums meet and turn against each other, the fibres are combed and arranged forming a web on the surface of the large drum.
2.4.4.2 Wet-laid

Wet-laid web forming methods are essentially a modification of the papermaking process (Jirsak and Wadsworth, 1999, p.65). Short staple fibres are dispersed in water forming fibre dispersion. As shown in Figure 16, this dispersion is deposited onto a moving wire screen or perforated drum and the water drained by suction to form a web. The web is then drained further and consolidated through pressing between rollers and drying. Both parallel and random fibre orientation within the web are possible using this method. Synthetic and natural fibres can be used but the process is usually limited to short fibres in the range of 2–6mm (Batra et al, 1999, p.49). The bonding process is achieved by the use of self-bonding cellulose fibres as in the papermaking process, or through the addition of chemical binders or thermoplastic fibres and subsequent heat bonding. Batra et al (1999, p.49) explain that the resulting nonwovens have relative isotropic properties.
The similarities between wet-lay web forming methods and paper-making processes make the link between this type of nonwoven construction and with hand-based papermaking processes clear. This suggests that the design possibilities for wet-laid nonwovens are potentially as those for paper.

2.4.4.3 Spun-laid
Spunlaid techniques, as shown in Figure 17, were developed between 1950 and 1970 (Kittleman and Blechschmidt, 2003, p.188). The spunlaid process involves the formation of webs directly from polymers in one continual process. Thermoplastic fibre forming polymer granules are melted resulting in molten polymer that is extruded through spinnerets to form continual filaments. These filaments are rapidly cooled and laid down on a conveyor belt to form a web. The cooled filaments are laid in a continual spiral arrangement resulting in a visible elliptic structure of fibres (Kittleman and Blechschmidt, 2003, p.201). The web is then bonded by heat and pressure using calender rollers, creating what are known as spunbonded nonwovens (Batra et al, 1999, p.51). Spunbonded fabrics have the advantage of high strength, but due to the choice of raw materials that can be used the process is restricted (EDANA (2), 2006). The thickness and quantity of the extruded fibres can, however, be controlled enabling a range of fabric densities to be achieved.

Due the industrial and chemical nature of the raw materials used and the technologies required to process them, it is difficult to draw direct parallels with hand based processes.

Figure 17: The Spunbonding Process (Batra et al, 1999, p.51).
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Other Polymer Based Techniques

Within the spunlaid area, further specialised web-forming technologies exist. These methods usually involve web-forming and web-bonding methods that take place at the same time enabling economical production (Kittleman and Blechschmidt, 2003, p.204). Such methods include meltblowing and flash spinning. Melt-blowing, like spun-laying, involves the extrusion of thermoplastic fibre forming polymers. The extruded polymers are blown through an air stream and collected on a screen or belt forming a web. The fibres are laid together and bonded through a combination of entanglement and cohesive sticking (Batra et al, 1999, p.53). In the flash spinning process, polymers are dissolved in a solvent and sprayed into a vessel. The solvent is then evaporated leaving a web of fibres that is further bonded using hot calender rollers.

2.4.5 Web-bonding

Most webs have little structural integrity (strength) in their unbonded form. Therefore the webs are consolidated through one or a combination of three main methods – mechanical bonding, chemical bonding and thermal bonding.

2.4.5.1 Mechanical Bonding

Mechanical bonding essentially involves the strengthening of fibre webs through physical entanglement. The two most common methods of mechanical bonding are needle-punching and hydro-entanglement which is also called spun-lacing.

**Needle-punching**

In the needle punch process, as illustrated in Figures 18 and 19, a series of barbed needles that are attached to a board are pushed and pulled repeatedly through a moving web that is sandwiched between holed surfaces called ‘bed plates’ (Batra et al, 1999, p.60). The needles hook tufts of fibre and pull them vertically through the web entangling and interlocking the fibres.

Since the development of this technology in the late 1800s a number of types of needle-loom have been developed that enable the production of ribbed and velour fabrics (Jangala and Huang, 1999). Structuring looms utilise forked rather than barbed needles which carry fibres into channels rather than through bed plates, producing a nonwoven with a ribbed surface. Velour looms utilise what is called a bristle brush bedplate system enabling a pile on the surface of the nonwoven to be achieved. Further technology exists that enables a patterned structure to be punched into the surface of a nonwoven. The needles are arranged on the needle board in the desired pattern and rather than being continually punched, the web...
remains still and is punched at carefully controlled intervals enabling the pattern to be transferred to the fabric structure (Marsden, 1977, p.25). Most fibre and web types can be used in the needle punch process.

The concept of entangling fibres to create a fabric structure relates directly to traditional felting processes. Therefore, the design possibilities in felting that are based around the entanglement of fibres are potentially possible in the needle punch process. The concept of needle punching is also used in hand-based textile techniques particularly in relation to felting. McGavok and Lewis (2000, p.40), in their guide to felt making, document the use of small needle punching tools with either a single or six barbed needles. They describe that single needle tools can be used to attach fine details to a piece of felt or to shape a solid piece of felt with contours. It is suggested that the six-needle tool be used to tack details onto dry fleece before felting. McGavok and Lewis (2000) point out the possibilities of designing with an industrial needle-punch through needling additional fibres and fabrics into the surface of webs.

![Figure 18: Needle Punch Process (Albrecht et al, 2003, p.271).](image-url)
Hydro-entanglement

In the hydro-entanglement process fine, high-pressure jets of water are used to entangle fibres. As illustrated in Figure 20, the fibre web is placed onto an entangling substrate, for example, a wire mesh (Jirsak and Wadsworth, 1999 p.88-89). Fine water jets are then applied to the web causing the entanglement of individual fibres. The entangling substrate is supported by a perforated drum that allows water to drain. After one or both sides have been entangled, the fabric is dried. The resulting fabrics are usually perforated in a pattern that mirrors that of the supporting wire.

The hydro-entanglement process is also known as spun-lacing as the arrangement of jets can give a variety of visual effects that have lace like qualities (EDANA (2), 2006). The process results in fabrics that in comparison to other nonwovens are particularly soft and have good drape, handle and strength (Jirsak and Wadsworth, 1999, p.91). Like spun-laying, the industrial nature of hydro-entanglement means that there are no direct hand-based processes that it can be compared to. However, although relatively rare and expensive to use, small-scale equipment does exist that shows potential for design experimentation.
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2.4.5.2 Chemical Bonding

Chemical bonding involves the application of liquid based bonding agents to fibre web and the 'triggering-off' of bonding by heat treatment (Ehrler and Schilde, 2003, p.369). These liquids are usually in the form of polymer dispersions (for example latex) or polymer solutions (Jirsak and Wadsworth, 1999, p.92). The most commonly used polymers are acrylate polymers and co-polymers, styrene-butadiene copolymers and vinyl acetate ethylene copolymers. Water based solutions are predominantly used but some powdered adhesives, foams and organic solvent solutions are also utilised (EDANA (2), 2006). Such solutions are applied uniformly using impregnation, coating, printing and spraying methods. Chemical bonding can also be used to colour webs by adding pigments to the binder solutions.

**Impregnation**

Methods of chemical bonding through impregnation essentially involve dipping the web in the binding solution. The saturated web is then squeezed between rollers to remove excess binder, and dried and cured using heat. Figure 21 shows an example of saturation bonding technology.
Spraying

In spray bonding, the binder is applied to one or both sides of the web using high-pressure spray guns (Jirsak and Wadsworth, 1999, p. 94). The spraying process is usually used to produce voluminous fabrics (ibid). The advantages of this method include the ability to use exact doses of binder without the need to squeeze off excess solution. Disadvantages are the comparative low strength of the fabrics produced and the expense of the technology involved (ibid). Figure 22 shows the spray bonding method.

Figure 21: Saturation Bonding (Jirsak and Wadsworth, 1999, p. 93).

Figure 22: Spray-bonding (Batra et al, 1999, p. 56).
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Printing

Print bonding methods are based on traditional textile printing technologies. The binding solution is printed onto the web using either patterned rollers or rotary screens. The solution is applied either in specific areas or over the entire surface of the fabric. Figure 23 shows the essential elements of this process. This method has clear links with traditional hand-based textile printing methods. The use of chemical binders in textile printing to adhere pigment to fabrics links print-bonding technologies with traditional processes in terms of material as well as method. Links can also be made with methods of silk papermaking in which binding solutions are painted through a mesh or screen onto a fibre structure to provide structural integrity and consolidation.

![Rotary Screen Diagram](image)

**Figure 23: Rotary Screen Printing for Chemical Bonding (Jirsak and Wadsworth, 1999, p.118).**

2.4.5.2 Thermal Bonding

Thermal bonding utilises the thermoplastic properties of certain synthetic fibres and binding powders to form bonds under controlled heating (EDANA (2), 2006). Binding powders are produced by dispersion polymerisation or grinding polymer granules. Bonding fibres are usually of a mono-component or bi-component nature. These fibres are blended into the main matrix of the web and when heated to their glass transition temperature they liquefy and surround the main fibres, bonding them at the fibre intersection points (Spindler, 2003, p.134). Bonding fibres are often selected because of their glass transition temperature and subsequent suitability for use with other fibres. The thermal resistance required of the end-product also impacts upon choice of fibre. A number of methods are used to apply heat to webs with a thermoplastic component including calendaring, through-air bonding and ultrasonic bonding.
Calendering

Calender bonding, as shown in Figure 24, uses heat and pressure applied through rollers to weld fibre webs at high speeds. The fibre layer passes through a nip between the two rollers of which either one or both are heated. The fibre layer is compressed and heated. The heat liquefies the thermoplastic fibres and aided by the pressure they surround the other fibres in the web locking them in place as they cool (Spindler, 2003, p. 134). The temperature at which the fibres are bonded is based upon temperature at which the fibre begins to soften (it's glass transition temperature). Up until a certain point the higher the temperature is raised above this the more the fibre runs and the greater the extent of bonding that occurs. Embossed or engraved rollers are used to bond at specific points. An embossed roller bond's the web only at the raised points of it's surface. This enables strong, lightweight and low loft fabrics to be produced (Batra, et al, 1999, p.). Calendering is also used as a finishing process to create patterned or textured embossed surfaces, or a smooth, shiny finish.

![Figure 24: Calender Bonding (Batra et al, 1999, p. 57).](image)

The availability of fusible fibres within craft spheres has led to the development of hand-based fabric making techniques that in many ways mirror thermal-bonding processes that utilise heat and pressure. 'Angelina' hot melt fibres are the most predominant products on the market and publications documenting and instructing in their use now exist (Midgelow-Marsden, 2003). Such fibres are used to create what are essentially thermally bonded nonwovens. The fibres are laid out by hand to create webs of various thicknesses. They are then fused together using a domestic iron. The resulting sheets are used either as decorative fabrics in their own right or in combination with felts and papers.

Midgelow-Marsden's (2003) 'A Work book for Fusible Fibres' documents numerous techniques for working decoratively with this process including, embossing, appliqué techniques, gilding, foiling, laminating, embedding and moulding.
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Through-Air Bonding

Through-air bonding takes place through the use of a controlled hot-air stream. As shown in Figure 25, the web (containing a thermoplastic component) passes through a chamber in which controlled hot air accumulates. The hot air is drawn through the web by a fan causing the thermoplastic components to fuse. This process enables voluminous or bulky fabrics to be produced.

In terms of hand-based textile processes, through-air bonding relates in some ways to the use of specialised heating tools. Tools such as heat guns work in a similar way to hair dryers enabling hot air to be directed onto or through textile surfaces. Midgeglow-Marsden (2003 p.9) notes that such tools are used to dry wet surfaces and to mould foam, plastic and thermoplastic materials for decorative purposes. These tools could potentially be used to bond fibre webs with thermoplastic properties.

Ultrasonic Bonding

In ultrasonic bonding the fibre web is drawn between an ultrasonic ‘horn’ and a patterned roller. The horn produces high frequency sound waves. The energy produced is transferred from the horn into web. This energy is changed into heat inside the fibres increasing their temperature and prompting fusion between the raised points of the pattern roller (Jirsak and Wadsworth, 1999, p133). This process is shown in Figure 26.
Ultrasonic bonding is predominantly used within industry. However, over the last ten to fifteen years the process has been explored in terms of its potential for use within design. For example, Janet Stoyel’s (2003) research investigates the use of ultrasonic methods to pattern fabrics with a metallic component and Janet Emmanuel’s (2003) work explores its potential to bond a range of textile substrates for sculptural purposes.

![Figure 26: Ultrasonic Bonding (Jirask and Wadsworth, 1999, p. 111).](image)

### 2.4.6 Finishing
Bonded webs produced using the methods outlined above can be sold as roll goods in their manufactured state or go on to further processing. Finishing processes form an important aspect of nonwoven production. Both traditional and specialised textile-finishing processes are used. Various methods of creping, embossing, coating, perforating, laminating, printing, flocking, surface fusing, moulding and shearing are utilised to enhance and add certain fabric properties for specific end uses (Stukenbrock, 2003, p.411-415). Creping and embossing are used to change the surface properties and handle of nonwovens for example softening, glazing or increasing bulkiness (Batra et al, 1999, p.62). Treating nonwovens with resins increases their strength and perforating them can increase their porosity (ibid). Laminating is used to create composite materials through fusing layers with different characteristics enabling fabrics with complex properties to be achieved (ibid). Printing can be used to add decorative qualities for interior applications and electrostatic flocking to enhance the surface qualities of fabrics for the shoe and automotive industries. Other properties that can be achieved through finishing and converting include; breath-ability, absorbency, repellency and fire resistance.
Within this research, finishing processes used within both textile manufacture and papermaking, are explored in terms of their potential to enhance specifically designed needled and thermally bonded nonwoven fabrics.
2.5 Part Four: Nonwovens in Design

2.5.1 Introduction
The previous sections have outlined the history of the nonwovens industry and identified that its development has been focused almost solely on the economic production of fabrics that replace or act as alternatives to traditional textiles in utilitarian or functional applications, and the development of engineered fabrics for technical end uses. Nonwovens are, however, being increasingly employed for aesthetic purposes, and technologies employed in nonwoven production have begun to be explored by textile artists and designers.

The first part of this section will assess the ‘visible use’ of nonwovens in products situated in a number of design contexts including; couture and mainstream fashion, sculpture, jewellery, textile art, interiors and other textile making activities. The second part will outline research into the development of nonwovens for specific design applications and the use of nonwoven processes by design practitioners including; needle-punch, thermal bonding, stitch-bonding, hydro-entanglement and chemical bonding. The discussion argues the need for further investigation into the task of designing for nonwovens from both practical and contextual perspectives and highlights specific areas for study.

2.5.1.1 Scope
Within Art and Design research, a substantial literature review to establish all previous and current work within the field of inquiry and subsequently the current level and extent of knowledge available within the domain is required (Durling, 2002 p.84). The infancy of formal research within the area of design means that current knowledge is often embedded within commercial products, creative works and practitioner and journalistic accounts of the artefacts produced. The review therefore utilizes a number of sources including; exhibition catalogues and reviews, practitioner accounts, textile journalism and insights gained through trade fair visits, alongside conference papers, academic texts, research theses and reports.

2.5.2 The Visible Use of Industrially Produced Nonwovens
Within this section of the review, the application of nonwovens in both fashion and interior design contexts will be reviewed. Sculptural and decorative applications are covered as is their use in textile making.

2.5.2.1 Fashion Applications
Within fashion, the use of industrial nonwovens at a couture level is explored and the development of nonwovens for use in mainstream apparel is outlined.
One of the first visible uses of industrially produced nonwovens within a fashion context was the employment of Tyvek® in Hussien Chalayan’s Autumn/Winter Collection 1995/1996. Tyvek is an extremely strong, machine washable nonwoven that is resistant to a number of chemicals (Dupont, 2002, p.2). Although often described as Tyvek Paper or Envelope Paper, the material is actually made using olefin in a spunbonding process which can be manipulated to create a hard or soft structure (Dupont, 2002, p.1). Due to its aesthetic similarity to paper, Braddock and O’Mahoney (1998, p.21) highlight the reference made by Chalayan’s use of Tyvek to disposable paper dresses of the 1960’s. They suggest that, Tyvek provided Chalayan with an alternative to paper that enabled a more permanent form of fashion and a distinct aesthetic to that of paper. Although citing Chalayan’s discovery of Tyvek as lying in bonding paper to fabric, an interview with the designer in The Observer (2001) suggests conceptual reasons for its use. Tyvek’s association with envelopes and the potential to produce affordable pieces en masse were suggested as important factors in Chalayan’s choice of material.

The performance characteristics of such nonwovens that result in their ability to be cut cleanly, tear resistant and non-fraying qualities have attracted a number of designers. For example designers Lesley Sealy and I.E. Uniform have taken advantage of the tough nature of Tyvek as well as the decorative potential of nonwovens as a components within textile surfaces. The image shown in Figure 27 shows a gossamer thin glossy nonwoven layered with printed fabric and embellished with glitter. Figure 28 illustrates the use of cut strips of Tyvek appliquéd to a base for a layered skirt by I.E Uniform.
As well as the technical potential afforded by nonwovens, Braddock (1998, p. 21) suggests economic advantage too as 'nonwovens are cheap to make, money can be spent on finishing treatments to produce a wide range of looks'. This is echoed by O'Mahony's (2000) assessment that 'a combination of low cost and ironically their very lack of aesthetic appeal has attracted the attention of fashion designers who have a strong interest in textiles'. In these examples, it seems that specific industrial nonwovens have been selected through a combination of aesthetic, technical and conceptual considerations. Its ability to be manipulated and reconfigured through personal making processes seems a crucial factor. The outcome, as Braddock (2005, p. 21) suggests, is the 'impartation of a craft approach to technical material'.

Although utilised as couture fashion fabrics, the visible use of nonwovens in everyday apparel has been limited because it is not breathable and has poor drape. Although suitable for specialised protective garments, it is not suitable for widespread use in clothing. This is the case with most nonwoven fabrics as they currently stand. However, extensive research is being undertaken by a number of groups including the nonwovens research group at Leeds University into the technical engineering of nonwovens suitable for clothing and garment construction techniques that are sympathetic to nonwoven properties.

The Development of Nonwoven Apparel

The inherent characteristics of nonwovens have in general deemed them unsuitable for clothing. However, advances in textile engineering have allowed the production of nonwovens with improved drape, handle and stretch. The elastic fabric developed by BBA, discussed in section 2.3, is one such example. The nonwovens research group at Leeds University is leading developments in nonwovens for apparel. Over the last two years the group have put on a number of fashion shows in conjunction with the fashion department at Leeds and the industry group Nonwovens Network. Both shows demonstrated the creative use of a wide range of industrially manufactured nonwovens. The collections of men's and women's wear garments displayed the potential of nonwovens in a more serviceable mode of fashion.

Research is being conducted into the identification of key property requirements of different clothing applications, and the subsequent development of nonwovens with properties suitable for specific clothing applications by the modification of macro and micro fabric structures (Nonwovens Research Group, 2005). The next stage, as identified by the research group at Leeds is to develop garment construction methods that are sympathetic to nonwoven fabric structures.
2.5.2.2 Decorative and Sculptural Applications

Under the heading ‘Decorative and Sculptural Applications’, the development of markets for industrially produced ‘decorative’ nonwovens will be outlined, and the use of industrial nonwovens by textile artists and designers to develop sculptural products and artworks will be reviewed.

**Developments within Industry**

Alongside Tvyek, another industrial nonwoven that has received considerable attention from designers is a material known as Colback®. The material made by a company called Colbond is made from bi-component polyester fibre using a process similar to spunbonding. Colback has high performance levels in terms of tensile strength, dimensional and thermal stability and mould-ability (Colbond, 2002). Colback is predominantly a reinforcing backing for carpets and car interiors and is made in a variety of weights and quantities. However, the distinct open structure and high gloss visual qualities of the material have prompted a number of decorative applications. Its high performance properties along with its decorative appeal have been exploited from both within and from outside industrial manufacture.

Colbond, as a manufacturer, has itself identified and begun to exploit the aesthetic potential of the material it produces. Through discussion with the UK representative for Colbond it was discovered that their products have found a niche market within the area of flower wrap. Initially the material is produced in a range of colours for this application and due the demand for variety, developments in terms of design have begun to be sought. Figures 29 and 30 show examples of nonwoven flower wrap that were shown at the ‘Maison and Object’ 2005 trade fair by ‘Guerin Createur’. Figure 30 shows a development from standard spun-laid structure to a fabric in which clumps of staple fibre have been added to create a more organic and varied visual surface quality. This is the only identified example of the development of a decorative market area from within the nonwovens manufacturing industry itself. In relation to traditional application areas for such products, the market for decorative products such as flower wrap is comparatively small at present (Colbond, 2002).
Within a completely different context, Colback has been used to a significant extent in the research and textile practice of Frances Geesin. Geesin (2005) explains that her first explorations with Colback were integral to her PhD research into the stiffening of fibres and fabrics and in particular an electrodeposition process. She notes that Colback was used initially because of its high strength in the process, its open structure and its cost effectiveness (ibid, p.102). In her PhD thesis Geesin (1995) explains that the material formed a base fabric with which to make electroplated and moulded vessels. The material is wrapped, in combination with other fabrics, around solid three-dimensional forms, heat treated and metalized. Geesin (1995) writes that the resulting objects ‘represent solidified space, surface containment and illusion – a good example of fragility and strength’. Exploring the creative potential of industrial nonwovens has formed a strong aspect of Geesin’s work to date. The use of Colback in particular, has characterised a number of collaborative projects with product designers, the results of which were outlined in a paper given at the Textiles Institute Conference, 2005. The conductivity of the fabrics is achieved through electrodeposition. The acid resistant property of the nonwoven enables this process (Geesin, 2005). Examples of Geesin’s work with Colback are shown in Figures 31 and 32.

**Figure 31:** Books, by France Geesin and Kaori Hosozawa 2003; carbon nonwoven knitted nylon fabric, electroplated copper and zinc; 6.25" x 4". (Lowenstein, 2004).

**Figure 32:** Cathedral Bowl, by Frances Geesin, 1998 Low melt fibres, copper and zinc passivate 760cm (Axis Arts, 2007).

**New Product Areas**

Geesin’s (2005) paper at the Textiles Institute Conference, 2005 outlines and demonstrates ‘alternative products and concepts for nonwoven materials and thermoplastics’ Geesin describes a collaboration between herself and Jewellery designer Scilla Speet, that involved treating Colback in passivation and PVD. Geesin notes that the process resulted in colour changes to the surface of the nonwoven. Fused to neoprene to give a supporting structure, the material formed the basis for a number of neckpieces. Geesin writes that a further collaboration with Jane Sturgess prompted the exploration of Colback as a material for bags.
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She explains that use of a high-strength Colback that could hold a fold enabled the development of metallised accessories.

When discussing a collaboration between the University of the Arts London and CERN (European Organisation for Nuclear Research), Geesin (2005) describes the use of Colbond as a base fabric to create partitions and lanterns for a gallery space. She notes that its affinity with scientific imagery was an initial factor in its choice for the project. In the projects realisation Colbond was successfully dyed using indigo and patterned through laser marking, ultrasound and heating processes that created a distortion of the original surface.

Geesin's work illustrates the decorative, conceptual and design potential of a specific industrially manufactured nonwoven and has perhaps pioneered the way in this area. From Geesin's lead, nonwovens such as Colback have been taken up by other textile practitioners researching industrial technologies within a creative context including Janet Emmanuel.

Conceptual and Technical Applications

Janet Emmanuel's (University of Brighton, 2005) research focuses on the adoption of processes associated with mass manufacture by artists and designers. Her doctoral research involved the assessment of ultrasonic welding processes on a number of textile substrates. In her paper 'Art and Industry: An Innovative Approach: New Textile Bonds using Ultrasonic Technology' Emmanuel (2003) explains that the experimental work involved the use of a number of industrially produced nonwoven fabrics including Texon T90, a felt like nonwoven used for underlay. Texon T90 was used as a cushion and support for a range of woven fabrics that were subjected to a telesonic welding process. She notes that embossed relief forms were achieved through bonding the two materials. Following this, four different types of Texon polyester nonwoven were assessed in this process. Emmanuel (ibid) writes that 'visual assessment of the material results were uniform' but that statistical analysis of the materials revealed differences in the behaviour of each material during the process.

Texon T90 and Texon polyester nonwovens were used throughout Emmanuel's study and were ultrasonically bonded to aluminium foil, perspex rods and Tyvek. Emmanuel explains that further experiments employed Colback W30 which led to the development of self-supporting three dimensional forms that combined the material with feathers, paper and metal. Emmanuel's research concluded in the production of three-dimensional forms that explore a juxtaposition of animal, mineral, vegetable, the body, cloth and its occupation of space (Emmanuel 2005). The structures, as shown in Figures 33 and 34, exploit the open, delicate and ethereal qualities of the nonwoven but also its ability to be manipulated and combined successfully, both in a technical and aesthetic sense, with a range of textile substrates in ultrasonic bonding processes (Emmanuel, 2003). The success of the work is
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evidenced in its inclusion in the European Textile Networks Exhibition ‘Artists at Work; New Technologies in Textiles and Fibre Art’ held at the museum of Textiles in Prato Italy in November 2003.

Figure 33: ‘Acoustic Shadow 3 Whisper’, Ultrasound Weld, Janet Emmanuel (Emmanuel 2003).

Figure 34: ‘Acoustic Shadow 4 Hush, Ultrasound Weld, Janet Emmanuel (Emmanuel 2003).

2.5.2.3 Interior Applications
The aesthetic and performance properties of specific industrial nonwovens have also been utilized within interior products at both mid and high ends of the market. The visual impact of open, glossy, web-like like nonwoven structures in combination with their ability to be laminated and bonded easily due to their sheet like, two dimensional form has attracted designers working in a number of product areas. Colback, Tyvek and other nonwovens with similar aesthetic and functional properties, are visible in a number of recent and current products including wallpapers, lights and interior fabrics. This section explores the use of nonwovens in wallcovering, lighting, floor covering and as interior fabrics.

Wallcoverings
Nonwovens have traditionally been used as a component part in wallcovering products, usually as a backing (Batra, 1999, p. ix). They are now, however, being used at the high end of the interiors market by companies such as Stereo (2004). Stereo specialise in materials-based wallcoverings. They work with architects and interior designers to produce wall coverings for the domestic and commercial interiors market. Their products utilise traditional materials for wallcoverings including grass-papers, linens and silks and a number of their ranges included nonwovens. Stereo’s (2004) company profile suggests that they perceive nonwovens as a contemporary material and produce a number of products that include open
structure nonwovens in combination with metallic finishes and in a range of subtle neutral tones, as shown in Figure 35. Paper-like nonwovens that exploit the possibility to include fine filaments in nonwoven structures are also produced by Stereo in neutral tones as shown in Figure 36.

Examples of similar products are also seen in collections by Aba Interior Surfaces, a USA based company who work in a similar market to Stereo and Vescom, a larger wall-covering manufacturing company. The uses of such nonwovens are also evident in the collections of interior companies Donghia and Ulf Moritz. Although the material make-up of these nonwovens is evident through company literature, the precise nonwoven processes used to make such materials are difficult to ascertain due to design confidentiality issues.

As well as forming the basis for new wall-covering materials, the performance properties of such nonwovens have prompted their application as an alternative to conventional wall covering papers and PVC materials in traditional products. For example, Cole and Son use what they describe as nonwoven papers in a number of their products. In an email discussion between the researcher and the Cole and Son design team, Cole and Son described that one of the main advantages of using nonwoven paper is the ease with which it can be hung. Because the paper does not need to be soaked like conventional paper, wallpaper paste can be applied to the wall rather than to the paper. They noted that the material can be used as both the backing and face of the product and that it provides a background texture that can be coated and printed onto.

Some such products are more distinctly 'nonwoven' than others are. Due to the aesthetic similarities of nonwovens with traditional papers, it is not always possible to differentiate what is and what is not a nonwoven in this context.
Lighting

As within the area of wallcoverings, in the area of lighting, it is often difficult to spot nonwovens. However, a number of specific examples within the mid to high-end market have been identified. A French interior company called Le Dauphin showed a number of nonwoven shades at the 'Maison and Object' 2005 trade fair. The drum and cone shaped shades shown at the fair were made from white polyester. The open glossy structure of long fibre filaments in randomly oriented arrangements suggests that the fabric was made using a spun-laid process, similar to that used to make Colback. The nonwovens used were very light in weight and density and had been laminated to supportive PVC backing.

The colourless nature of the product drew attention to the subtle visual texture of the nonwoven and the transparent, light weight two-dimensional quality of the material provided crisp clean lines and a slightly diffused glow. A similar polyester nonwoven was evident in a collection of hand made light shades shown at Chelsea crafts Fair 2002 by maker Melanie Darwin. The shades, shown in Figure 37, combined the nonwoven dyed in subtle pastel shades with denser woven fabrics to provide contrasts in opacity, surface structure and texture.

Perhaps one of the most evident uses of nonwovens in this area is that of Tyvek by Torj Bootnje. Bootnje exploits Tyvek’s high tensile properties and affinity to industrial cutting to produce intricately cut and layered fabrics. The material is structured in a self supporting manner around a ceiling bulb covered with a small protective shield. The product is shown in Figure 38.

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Figure 37: Light Shades by Melanie Darwin, 2002.

Figure 38: Midsummer Blue, by Torj Bootnje.
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The examples discussed relating to wall coverings and lighting show the potential of nonwovens in this product area but also highlight the anonymity of the material. Where the material is used for a supportive base or surface on which to print this anonymity is perhaps an advantage. It is suggested, and explored in later chapters, that in products where unique nonwoven structures and qualities are exploited this sense of anonymity may be a disadvantage to the success of the product.

**Interior Fabrics**

Within interiors it is evident that nonwovens are emerging as fabrics in their own right. Within this area, as in wallcoverings and lighting it seems apparent that light weight, high gloss, synthetic open structures are some of the first nonwovens to become visibly present in this area. Although some examples exist within the high end market, perhaps because of their economy these fabrics seems to have been applied in slightly lower market areas. What, again, appear to be synthetic spun-laid nonwovens, have been marketed as interior fabrics by French interior accessories company Becoming. Figure 39 shows the use of this type of nonwoven as a table covering. The fabric, produced in a range of deep colours and shown in multiple layers is also marketed as draping fabric. The fabric has a high sheen, smooth shiny surface and crisp handle. Similar fabrics are also sold for display and draping applications by the British Trading Company based in Nottingham. As shown in Figure 40 the fabrics are printed on using what appears to be a heat transfer process. Although the fabric has an almost silk like quality and gossamer weight, the fabrics retain a low-end feel because of the motifs and choice of colour in the print design.

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**Figure 39:** Nonwoven marketed as a table covering by Becoming, 2005.

**Figure 40:** Printed Nonwoven, British Trading Company.
This type of nonwoven is also becoming available through retailers such as Ikea. The low cost of production enables them to sell large quantities of the fabric for very little. Sold as a sheet material the fabrics are presented in store as drapes or hung fabric lengths to divide space. Such nonwovens are also evident at a much higher end of the interiors market as shown in Figure 41. The fabric, by Zimmer and Rhode, shows a glossy gossamer like layer of nonwoven appliquéd to a very light and open monofilament weave. The translucency of the two fabrics enables the formal structure of the weave and more spontaneous structure of the nonwoven to visually merge.

Figure 41: Ivy Fabric incorporating a nonwoven fabric, Zimmer and Rhode, 2005.

**Floor Coverings**

As well as being used as backings for floor coverings, nonwovens find a visible role in durable, economic carpets, particularly within the commercial and contract interiors sector. Stein (2003, p.516) explains that needled nonwovens are produced for this sector using predominantly synthetic fibres such as polypropylene and nylon. He writes that a two stage process is used to create products that can be produced from a combination of primary and waste fibres. As shown in Figures 42 and 43, two colour effects and ribbed surfaces can be achieved in the process.

Stein (2003, p.516) goes on to explain that high dimensional stability can be achieved by using reinforcing fabrics or back coatings. The high wear resistance of the fabrics often leads to use in the public sector, for example in schools, airports, hospitals and offices. He notes
that, the 'easy-care' properties such as stain resistance that are often required within such environments are usually achieved through appropriate finishing processes.

2.5.2.4 The use of Nonwovens in Textile Craft

Colback and similar nonwoven fabrics are also marketed as a 'craft' material alongside handmade papers. The product is sold under names such as 'Angelwire' and can be bought as a sheet material in a variety of weights and colours for use in the creation of hand made products such as greetings cards. Its ability to be dyed, pleated and heat bonded and the ease with which it can be manipulated has prompted wide use within 'lo-tec' craft production as well as academic research that utilises 'high-tec' industrial equipment.

Within the sphere of 'lo-tec' craft production, as highlighted previously, Tyvek has also become a prominent material. It is included in publications that outline alternative methods of textile manipulation for decorative work. As in other spheres of production, the product is perhaps unrecognisable as a nonwoven.

The availability of heat bondable fibres within the craft sphere has further expanded the use of what are essentially nonwoven materials and processes within a craft sphere. Polyester-based fibres that bond at relatively low temperatures are now available alongside fibres for felting and papermaking. The trade named 'Angelina' fibre is characteristically metallic and iridescent. The process used to create a fabric using these fibres echoes hand based felting processes and also industrial thermal bonding processes. The fibres are laid out in a similar way to the laying of fibre batts in felting and are sandwiched between two sheets of tissue or grease proof paper. They are then ironed at a silk setting. The application of heat and pressure causes the fibres to melt and bond around each other creating a nonwoven structure almost instantly. Within this sphere, the process almost provides an economic alternative to
more laborious hand based material construction processes such as felting, papermaking and weaving as the development of needle-punch did within the spheres of industrial materials at the onset of the nonwovens industry. As Braddock (2005, p.21) notes, that when using Angelina fibre, 'the user can move straight from fibre to fabric instantly'.

2.5.3 The Use of Nonwoven Technologies and Processes in Design Practice and Research
This section of the review outlines research into the development of nonwovens for specific design applications. It reviews the use of nonwoven technologies and processes by design practitioners including; needle-punch, thermal bonding, stitch-bonding, hydro-entanglement and chemical bonding. The discussion argues the need for further investigation into the task of designing for nonwovens from both practical and contextual perspectives and highlights specific areas for study.

2.5.3.1 Needle-punching
A review of relevant literature suggests that needle-punch is the most frequently explored industrial nonwoven process by designers. An initial study into the area was undertaken at Huddersfield University during the 1970s by Graham Marsden (1977) into the aesthetic potential of needle punch. Since then further research and product development has explored and exploited the needle-punch process for aesthetic purposes. Developments made by Marsden (1977), Tait and Style (1985–Present), Janette Appleton (2003) and Nuno (1995) are outlined below.

Research Conducted by Graham Marsden
During the 1970's research was conducted at the University of Huddersfield by Graham Marsden into the design of needle-punched nonwovens. His work asserts that the rapid growth of technology within the area of nonwovens had, prior to his study, taken place with 'little or no regard to the aesthetics of the resultant products' (Marsden, 1977). On identifying this, Marsden's research sets out to form a 'more coherent relationship between technology and design' in the specific area of needle-punched nonwovens. In summary, his work assessed the fibre-pick up characteristics of forked patterning needles in an attempt to control the amount and position of fibre transferred during each needle penetration (ibid). Within this, the effects caused by changes in machine variables on the pattern produced by a basic needle arrangement were investigated (ibid). The work resulted in the deduction of a sequence of pattern preparation requirements that would enable a design to be represented on paper prior to commercial production (ibid).
Further to this Marsden explored the use of textured fibres, controlling the placement of fibres within the web to achieve stripes of colour and punching yarns to the surface of the fabric.

**Tait and Style**

In regards to the commercial production of needle-punched fabrics but on a smaller scale of production, Tait and Style have successfully realised design collections utilising the technology since 1985 (Tait, 2004). Tait and Style, based in the Orkney Islands, was set up by Ingrid Tait. The Orkney base includes a pilot small-scale needle-punch unit on which the products are manufactured.

Tait writes that her first experiences of needle punching, in 1985 at Huddersfield University, were of its use to 'bond un-spun wool to make felted fabrics' (Tait 2004). Tait explains that her perception of the product as a resemblance of 'crude hand felt' led her to explore the potential of the process as a new bonding/embroidery technique with which to make innovative, modern, commercial fabrics. Swann (2002, p.32), describes Tait's use of needle-punching as a 'unique fabric fusing technique'. Examples of Tait and Style's needle-punched scarves products are shown in Figures 44-48.

![Figure 44: Needle-punched scarf by Tait and Style, 2005/2006.](image)

![Figure 46: Needle-punched scarf by Tait and Style, 2005/2006.](image)

![Figure 45: Needle-punched scarf by Tait and Style, 2005/2006.](image)
The images show the use of needle punching as embroidery and fabric bonding techniques as well as a means with which to create a base fabric. Figure 47 shows cut and layered needled nonwoven webs that have been bonded onto a tartan fabric using the needling process. Similarly, Figure 48 shows a delicate lace material needled into tartan fabric that had been needled to tartan fabric and fibre. The needle process has enabled a visible blending of the two distinct fabrics. Swann (2002) notes that the surface of such fabrics appear to have been painted.

The scarves shown in Figures 44 and 45, illustrate the use of needling to almost appliqué fabric motifs (figure 44) and slivers of fibre (figure 45) onto the surface of pre-constructed woven cloth. The lattice structured scarf in Figure 46 shows a fabric that appears to have been made through the punching of slivers of fibre and yarn that have been organised into a lattice structure and consolidated through the punching process.

Tait (2004) writes that over the years, her aim has been to push the boundaries of what can be done with needle-punching. She adds that she has only come across a hand full of novel and interesting fabrics by needle punchers and points out that most of them are Japanese. She notes that Tait and Style continue to explore the technique along side their design vision with the sense that as a technique the ‘best most innovative designs are still waiting just around the corner’ (ibid).

The development and commercial use of needle punch by Tait and Style is perhaps the best example of nonwoven technologies being used in consistent manner for the production of
‘designed’ nonwoven fabrics. It is interesting that it is this nonwoven technique that has been adapted to what could be described as a designer/maker mode of practice and that the development of ideas has evolved through a hands on exploration of process by designers.

Nuno

Japanese textile innovators Nuno have explored the possibilities of nonwovens from the perspective of their recycling potential and engineer-ability. Figure 49, shows a polyester needle-punched fabric that has been made from recycled plastic bottles. Braddock and O’Mahoney (2005, p.100) note that the fabric has been coated with a polyurethane resin providing aesthetic and functional properties similar to otter skin. The fabric has a smooth shiny surface, is breathable, provides warmth and is wind and waterproof.

Janette Appleton

As well as being used to produce commercial products, needle-punch has also been explored in the production of individual pieces or one-off textile art works. The potential of the process in this context is illustrated through recent works by textile artist and maker Janette Appleton. During her involvement with ‘Through the Surface’, a collaborative Anglo/Japanese textile project, Appleton and her collaborative partner Naoko Yoshimoto took up residency at Huddersfield University in order to utilise their pilot scale needle-punch equipment (Appleton and Yoshimoto, 2004).
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Appleton and Yoshimoto (2004) explain that during the period of collaborative work, concepts relating to nomadic travel and journeying were explored. Needle-punch, stitch and deconstruction processes were utilised, combining as Hoggard (2004, p. 29) writes, the 'most ancient cloth making technique with the most modern technology'. Extensive sampling using the needle-punch equipment was carried out, that focused on both the construction of needle-felt and the deconstruction of garments (Appleton and Yoshimoto, 2004).

The collaborative work resulted in the production of what Appleton (2004) describes as 'solid compacted felt surfaces' that were concluded through the realisation of a forty feet 'felt tapestry'. The piece, shown in Figure 50, illustrates the potential to graduate colour and the use of solid blocks of colour in a striped arrangement. Additional fibres and fabrics are incorporated through the needle-punching process to achieve a similar appliqué technique to that employed by Tait and Style.

![Figure 50: 'Landline: Double-Edged Encounters', wool, various fibres and fabric, transfer printed needle-punched felt, 2003.](image)

The success of the techniques employed in a large-scale composition points to further potential to use nonwoven processes to create large-scale fabric installations. The possibilities to work with innovative techniques, such as those outlined, in a consistent repeatable and potentially commercial way is an issue that is addressed within this research.

Involvement with Machinery

Appleton's reflections on the realisation of the work outlined above reveal something of the making experience in regard to needle-punching. Of the working process, Appleton (2004) notes that a 'concentrated period of working with the machines' enabled her to 'understand
their process' and see it as an 'extension of the hand as a creative tool'. Appleton also noted that the technical assistance and inventive attitude of the machine technician/operator enabled the full potential of the needling process to be explored within the context of their individual work. This suggests that there are factors beyond the capability of equipment employed that impact upon the innovation that can be achieved.

Nancey Tingey (2004) gives further insights into needle-punch used within this context, and in particular the relationship between maker and machine in regard to needle-punch in a paper given at the Tracking-Cloth Symposium at the University of Wollangong in Australia, March 2004. Tingey (2004), another textile artist who works predominantly with felting techniques, explains that she explores the possibilities of blending different merino wools and repeated needling to create 'track lines' on the fabric and the possibilities of cutting, reconfiguring and re-needling the resulting fabrics. Tingey (2004) observes that, when using industrial needle-punching processes, the artist's involvement is 'deceptively simple; it is the machine which orchestrates the complex procedures and carries out the hard work'. Of the relationship between operator and machine, she notes that 'a rhythmical relationship develops...as the work progresses' (ibid).

It is interesting to note that in both Appleton and Tingey's experience of the artists role in the needle-punch process it is clearly separated to that of the machine operator and that it is the work and experience of the latter that seems to determine the progression of the process.

2.5.3.2 Thermoplastics and Moulding
Further to the needle-punch process some thermal bonding techniques used within the nonwovens industry have been explored by textile designers and makers both as part of textile construction processes and as finishing or moulding processes. Much of the resulting work focuses on the realisation of three-dimensional form.

The term thermoplastic refers to a material's inherent ability to be formed through the application of heat. Enabling moulding, pleating and creasing, the thermoplastic quality of synthetic fabrics is an area of interest to textile and fashion designers. Exploiting such potential in synthetic nonwovens has been an initial area of investigation in textile designing and making. In terms of applications for nonwovens within fashion, Braddock and O'Mahoney (1998, p.20) suggest that the exploitation of thermoplastic properties may be the way forward.

As with the relationship between felting and needling-punching, it is suggested that new and/or industrial thermal bonding technologies have been pursued within this context because there is an established body of knowledge within textile making in relation to three dimensional felting and hand-based three dimensional forming techniques using heat and
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pressure. Two examples of the use of nonwovens and nonwoven technologies to create moulded three dimensional forms will be discussed in this section. The work of Marie Blaisse and Savithri Bartlett will be outlined.

Blaisse

One of the first explorations of moulded nonwovens within fashion was carried out by Dutch designer Maria Blaisse. Since the mid nineteen eighties, Blaisse has explored three dimensional form through the use of non-wovens in their broadest sense. Materials such as neoprene rubber and foam polyamides are used by Blaisse in conjunction with vaccum forming and lamination (thespacebetween, 2004). Influenced by these industrial processes and materials, more recently, Blaisse has translated ideas in woollen felted forms (Braddock and O'Mahoney, 2005, p.22).

Central to Blaisse's work is the interaction between the three-dimensional forms she creates, the body and movement. Betskey (2004) describes her work as 'non-woven forms for the body that are poetic and deceptively simple' and as the rescuing of 'mundane materials and old craft traditions'. He describes the materials Blaisse uses as 'mute' until they are realised in three-dimensional motion. In terms of process, the use and influence of traditional craft methods has been perceived as imbuing the work with 'veiled historic references and a sense of timelessness' (ibid). Betskey (2004) suggests that the 'process of working the material' is Blaisse's. This highlights the importance of personal interaction between maker, material and process within this context.

The significance of Blaisse's work has been compared to that of architects such as Alvar Alto and Frank Lloyd Wright (Palsby, 2004 in Blaisse, 2004). Blaisse's work has prompted other textile artists and designers to explore nonwoven materials as sculptural forms for the body. Savithri Bartlett, acknowledges the influence and inspiration of Blaisse's use of heat sensitive nonwovens in her research into the use of thermoplastic fibres to create nonwoven fabrics for three-dimensional applications in fashion (Bartlett, 1997).

Bartlett

The use of a thermoplastic bi-component polyester fibre to create fabrics that are aesthetically pleasing but have the structural integrity required of fashion fabrics formed the focus of Bartlett's research into nonwoven materials. Bartlett's Mphil. study, conducted between 1994 and 1997 at the Royal College of Art, outlines inquiry into the possibilities of creating nonwovens specifically for fashion applications using a thermoplastic bi-component fibre.
Chapter 2 Literature Review

The work was carried out using nonwoven pilot plant facilities at the University of Manchester Institute of Science and Technology. The experiments carried out in Bartlett’s research confirmed a number of possibilities inherent in the needling-punching process that were documented by Marsden. For example the use and manipulation of coloured fibres in the process to create striped or graduated blocks of colour (Bartlett, 1997, p.15–20), the incorporation of cut fabric pieces and fibre slivers into the fabric through the needling-punching process (ibid p.20) and the alteration of needle-depth to control the extent to which the fibres are entangled or fused (ibid, p.16-17).

Although a range of fibres were collated at the onset of the research (ibid, p.4), the experiments were conducted using predominantly acrylic fibres (p.15 – 20). However, the low strength of the fabrics achieved were considered as unsuitable for the intended purpose of fashion (ibid,p.21). A number of means of stabilising the fabrics were considered. The use of a range of fibres were studied to establish optimum fibre characteristics for improved strength – extensive length, high strength and reduced fibre diameter (ibid, p.21). Further processing such as stitching and stiffening were considered but Bartlett notes that ‘gain in fabric stability was off-set by a forfeiture of aesthetic considerations’ (ibid, p.23). To overcome this dilemma, a thermoplastic polyester fibre produced by a company called Wellman International was incorporated (ibid, p.25). The needled fabrics containing the fibre were then subjected to a number of thermal bonding processes. The resulting fabrics were found to have improved strength and so formed the basis of the inquiry.

Both wool and acrylic fibres were blended with the thermoplastic fibre in various ratios and their strength in relation to the intended fashion use was assessed. The fabrics revealed that 100% thermoplastic fibre was needed to create a fabric with suitable strength for the intended purpose. The resulting needled nonwoven was thermally bonded using a heat-transfer press and used to create thermo-formed fabrics (ibid, p.41). The appeal of these fabrics within the context of couture fabrics was confirmed through use by fashion design duo ‘Boudica’ for moulded bodices in their spring/summer 1998 collection, as shown in Figures 51 and 52. Using fibreglass moulds and industrial ovens, the fabrics were formed into a series of sculptural bodices.
The results of Bartlett's research highlight and document a number of the potentials in needle-punching that have been exploited by textile designers and makers. Her work also begins to unearth the aesthetic potential of thermoplastic fibres within the nonwoven web. Her work, however, focused on achieving fabrics with high strength and thus the use of 100% bi-component fibre within the fabric, and her use of thermal bonding as a secondary to an intensive punching process. The results are successful in their context and reveal the sculptural potential of the fibres to create dense, hard, three dimensional forms. The work does not, however, exploit or assess the potential of thermoplastic fibres to work alongside a variety of fibres to create visually and tacitly diverse nonwovens. From this perspective, Bartlett’s work in a number of ways has formed one of the starting points for investigations within this research, particularly in the exploration of thermal bonding using fusible fibres in conjunction with a range of natural and synthetic fibres. Further details on the influence, expansion and development from this work will be highlighted in the relevant experimental chapters that follow.

2.5.3.3 Hydro-entanglement and Stitch-bonding

The processes of Hydro-entanglement and stitch-bonding have been less explored within a design context perhaps due to the lack of availability of pilot scale equipment within the area. However, a number of projects are being conducted by larger research groups who have greater access to the required technology than individual designers or practitioners that focus on design. The following two examples highlight the work that is currently going on in this area in terms of utilizing the technologies for design purposes. The examples illustrate a focus on finishing processes. From a contextual perspective, this area of nonwoven
production highlights some of the potential obstacles faced by designers in utilising such technologies.

**Hydro-entanglement**

Hydro-entanglement, as outlined previously, is a process in which high pressured jets of water act in a similar way to needles in entangle and bond fibre webs. The Nuno Corporation have utilised the hydro-entanglement process to embed fabrics within the surface of nonwovens, in a similar way to which needle-punch has been used to incorporate fabric elements into needled webs (Birnbaum and Sudo, 1997). Figure 53 shows a Nuno fabric in which fabrics have been embedded into a nonwoven using the pressured jets of water.

![Figure 53: Nonwoven Fabric, Nuno Corporation, 1997.](image)

Exploration of this process by textile designers and makers may have been limited to date due to limited opportunities to access the appropriate technologies. The nature of research conducted by creative practitioners often necessitates the need for hands on access to equipment therefore making it difficult to explore limited and expensive technologies such as this.

**Stitch-bonding**

The inclusion of stitch-bonded fabrics within technical classifications of nonwoven is debatable. There have, however, been a number of interesting developments in regard to the use of stitch-bonding technologies to create fabric for apparel. Through a move to develop and expand the wool industry within New Zealand and Australia, over the last two to three
years the Wool Research Organisation of New Zealand has explored the development of merino wool nonwovens for applications with apparel. Alongside developments for outerwear linings, the group have developed stitchbonding techniques to create light weight, three-dimensional and stretch nonwovens (McFarlane, 2005).

McFarlane's paper given on behalf of the Canesis Group at the Nonwovens Network Conference in May 2005, illustrated the potential to create stitch-bonded nonwovens with three-dimensional texture. The group have used a shrink resistant finish in combination with a woollen stitch-bonded fabric. McFarlane (2005) explained that when the fabric is subjected to a shrinking process, the exposed areas of fabric contract around the floral resists and create a textural surface.

As well as pointing to the potential of stitchbonding to create flexible fabrics for clothing, the work highlights the potential of finishing techniques to add design value and alter the surface structure of nonwovens. The concept of building into the fabric the necessary properties to be used in particular finishing processes forms an important aspect of exploration within this research.

2.5.3.4 Chemical Bonding

Chemical bonding has also been touched upon by designers for application within creative contexts. Although this area seems to have been explored to a lesser extent, examples exist of the exploitation of the opportunity to bond or laminate nonwoven webs by means of chemical adhesion for design purposes.

**Julia Keyte**

A project undertaken by Julia Keyte as part of an initiative called 'Hi/tec Lo/tec' enabled the realisation of decorative nonwoven panels. The initiative, conceived and managed by the Crafts For Now consortium in the South West of England, focused on the way in which a number of contemporary designers and makers are developing new materials that have industrial origins (O'Mahoney, 2000, p.3). The project involved the placement of designer/makers in industrial contexts. The intention was for the participants to explore the technologies available from their perspective as creative practitioners.

Keyte, a jewellery designer, undertook a placement at BBF Nonwovens. Based in their manufacturing laboratories, Keyte's twenty day placement involved the experimentation with cutting, colouring and fusing industrially made chemically and thermally bonded nonwoven materials. Figure 54 shows one of the fabric panels created, as Keyte explains, from two sheets of chemically bonded fabric and one thermally bonded fabric coated with an adhesive
substance (O'Mahoney, 2000, p. 21). The fabrics were printed with acrylic pigment and cut using a piece of equipment conventionally used to create test fabrics. Keyte goes on to describe that one of the chemically bonded fabrics was fused to the thermally bonded fabric and the third fabric interlocked through the circular structure created by cutting (ibid).

Of her experience, Keyte describes the equipment she had access to in the companies research laboratories as being comparatively 'lo-tec' (O'Mahoney, 2000). On reflecting on the placement Keyte observes that within the context of an industrial nonwovens manufacturer, new technology is only used to aid speed and economy in mass production and notes that the methods of working used by the technical staff in the laboratory were similar to her own craft production methods (ibid). O'Mahoney notes, that the difference between Keyte's approach within this context and that of the manufactures was most notable in regard to their perceptions of scale. This was evident in terms of the scale of manufacture and the detail in which the processes were considered (O'Mahoney, 2000 p. 6 and 9). The difference in the level of technology used in nonwoven research laboratories and that used on larger scales of manufacture is explored and highlighted as an important consideration in the development of designed nonwovens within this research.

2.6 Summary
This chapter has presented the contextual, historical and technical framework within which this research is positioned and has outlined previous and current research, product development and design practice that relates to the application of nonwovens and nonwoven
technologies within design.

Part One outlined various approaches to design within textiles. The relationship between craft and industry and the role of craft knowledge (the value of hand-work) in regard to textiles was discussed. The relationship that currently exists between craft and Industrial modes of production in regard to nonwoven manufacture was brought into question, in particular the notion of developing designer maker practice and class production within this area. Key factors in developing successful working partnerships between designers and makers and industry were also highlighted. Part Two, provided a brief overview of the history and development of the nonwovens industry, through which connections between textiles produced using traditional craft processes and nonwovens were highlighted to draw attention to the potential cultural and decorative significance of nonwovens. In Part Three, nonwoven technologies were outlined. Attention was drawn to parallels between hand-based textile processes and industrial nonwoven production methods and technologies.

Part Four reviewed past and current research relating to nonwovens and design (from a predominantly aesthetic perspective). The review confirmed that there is a lively interest in the use if nonwoven materials and technologies within the textile community. It highlighted that many designers have employed industrially produced nonwovens for decorative means within textile installations and products. The nonwovens employed, for example Colback and Tyvek, are often synthetic and have a functional or technical aesthetic. Reviewing the use of nonwoven technologies revealed that the needle-punch has been the most commonly explored nonwoven process by designers to produce felt like fabrics. Thermal bonding methods (Bartlett, 1997), hydro-entanglement (Nuno, 1997), and stitchbonding (McFarlane, 2005) have, however, been touched upon and the potential to add further value to nonwovens through innovative finishing processes (McFarlane, 2005) has begun to be explored. Bartletts (1997) research, highlighted the potential for further research into thermal bonding, from an aesthetic perspective and the work conducted by the Canesis Group highlighted the potential to combine construction techniques and finishing processes for aesthetic means (McFarlane, 2005).

Having established this, the initial focus of this research, from a practical perspective is on nonwoven methods other than needle-punching, in particular thermal bonding, and the use of finishing processes to add further aesthetic interest to the fabrics produced.

Part Four of the review also highlighted that most designers exploring nonwoven technologies have started from the point of small scale industrial equipment. This brings into question the relevance of hand-processes to industrial production. In order to clarify this, the first period of practical work conducted focuses on the development of hand based nonwoven methods of
construction. The first research question (What aspects of industrial nonwoven technologies can be appropriated using hand-based textile process?) is thus addressed.

The methodological approach taken to address this, and the further four research questions will be discussed in the next chapter.
3.1 Introduction

This chapter describes the methodology and methods used within this research. Before doing this, the notions of research, methodology and method are outlined, and some perspectives on approaching research in textiles are outlined.

3.1.1 Research, Methodologies and Methods

Within the fields of Art and Design, the notion of 'research' is used to describe a number of different activities including information gathering and collection, searching out sources of inspiration and experimenting with new materials and techniques (Durling, 2000). 'Research' in the traditional sense, however, requires a different understanding. Research can be broadly defined as systematic inquiry. In order for inquiry to be systematic, appropriate methodologies and methods must be used.

A methodology can be described as a strategy or plan in regard to a particular inquiry (Creswell, 2003 p.5 and Walliman 2001, p 6).

Research strategies or plans can be described as either quantitative or qualitative. Creswell (2003, p. 18) summarises that quantitative approaches to research use positivistic claims when developing knowledge, for example, notions of cause and effect, reduction to specific variables and the use of measurement and observation (ibid). A quantitative approach is appropriate when an inquiry seeks to count and assess numbers (Walliman, 2001, p. 20) by collecting statistical data using predetermined instruments (Creswell, 2003, p.18). Quantitative research employs strategies of inquiry such as experiment. (ibid) Qualitative approaches to research, Creswell (2003, p.18) summarises, are those in which constructivist perspectives on knowledge are used, for example, considering the multiple meanings of individual experiences with intent to developing a theory or a pattern (ibid). Qualitative approaches are required when an inquiry concerns the nature of something and seeks to evaluate its qualities (Walliman 2001, p.20) by collecting open-ended emerging data with the intent of developing themes from that data (Creswell, 2003, p.18). Qualitative approaches to research employ strategies of inquiry such as case study (ibid). A 'mixed methods' approach involves the collection and analysis of both quantitative and qualitative data in a single study.

Research methods are the specific ways in which research data is collected and analysed within the inquiry (Cresswell, 2003, p.17).

3.1.2 Approaching Research in Textiles

In discussing the nature of textiles as a subject, Gale and Kaur (2002 p. ix) write that 'there are so many facets ...that the subject pretty much defies attempts to sum it up'. Textiles as a
research subject is broad and encompasses both art and science. Within the textiles industry, new products are developed by both designers and engineers. Depending on the context in which the research is situated or the intended end-use of the product being developed, both engineers and designers conduct research and make design decisions. For example, as Wilson (2001, p. 2) notes, in the case of medical textiles where performance is paramount, engineers will conduct research and make design decisions. In applications where the appearance of the textile is the priority, designers trained in aesthetics will conduct research and make the decisions. The approach to research taken by each may often be quite different.

John Broadbent's paper 'Generations in Design Methodology' (2003), examines the relationship between design and science in regard to methodology. Broadbent highlights several differences between the scientific and design led approaches. Some of the key differences he notes are that 'science seeks objective truth whilst design aims to satisfice', 'scientists seek global solutions, designers seek local ones' and that 'scientific methodology is well suited to determinate problems, whereas design methodology addresses ill-defined, unique context dependent problems (ibid, p.7). This research is approached from a design rather than scientific stand-point.

3.2 Methodology

Antilla (1995) highlights that the choice of methodological approach when researching textiles (and clothing) relates to the nature of the research questions being asked and the context in which the research is situated.

This research is set within the context of designer maker practice, the central proposal and subsequent questions addressed within the work concern the nature of designing and making nonwoven fabrics for niche, high-end interior markets. The research presented seeks to; assess and explore the nonwoven processes, in question from a creative perspective rather than to quantify specific aspects of them; to evaluate the fabrics produced, from an aesthetic perspective, rather than to test their physical properties and; to understand the impact of manufacturing opportunities and limitations relating to the processes and fabrics in question. Therefore, a predominantly qualitative approach has been selected that enables a creative dynamic to be central to the research that has been developed.

As well as being set within the context of designer maker practice, the aims of this research are reflected within the professional activity of designer maker practice. The notion of designer maker practice is therefore central to this research and has informed the approach taken.
3.2.2 Research that Involves Practice

Research in which art or design practice is the central research strategy has been coined as practice led or practice based research. These strategies, Gray (1996, p.1) writes, began to emerge during the 1970s and early 1980s when artists and designers saw the potential to explore practice through the framework of higher degrees. Gray notes that the development of such strategies has been concurrent with a paradigm shift in most areas of thinking. As such, she notes, post-modern rather than modern ideas impact upon the way we relate, communicate and generate knowledge. She describes practice-led research as 'research that is initiated in practice, where questions, problems and challenges are identified and formed by the needs of practice and practitioners and secondly that the research is carried out through practice, using methods specific and familiar to practitioners within the visual arts'. Durling (2002, p.82) describes it as a study in which practice is used as an interrogative process.

Practice-led research has, however, been the focus of much debate within the broader academic community and as such, has come under much criticism. Several critiques highlight that some frameworks of 'practice-led' research allows art-practice methods to be research methods for research relating to art practice (Love, 2006, p.3 and Durling, 2002, p.82). Durling (2002, p.81) argues that practice alone cannot form a research strategy as its goals are quite different to those of research. He highlights that research asks questions, objectively analyses and disseminates conclusions unambiguously. However, he writes that practice may form part of a PhD research study if it is used as a structured method for collecting data systematically, or as a means to allow structured reflection on action (ibid, p.82). In addition to this, Durling (2002, p.83) suggests that whilst new knowledge is embedded within artefacts produced through practice, the process undertaken to realise the artefact is often not communicated through the artefact itself. Therefore the knowledge gained through the art or design process, must be made available and transparent by the systematic documentation of practice and structured analysis.

As alluded to above, designer maker practice is central to the aims of this work and therefore forms an important aspect of the research methodology. A research approach in which practice is an element of the research strategy has been employed.

3.2.3 Naturalistic Inquiry

Gray and Malins (2004) outline several approaches to research involving practice that have been developed by art and design researchers since the late 1970s. Naturalistic Inquiry is one of these approaches.
Naturalistic Inquiry is a social science research approach developed by Lincoln and Guba (1985) that embraces constructivist perspectives on knowledge (Robson, 1993, p.27). As such, the approach is qualitative and involves the use of research strategies which enable multiple perspectives relating to the subject in question to be evolved. As, Gray (2004, p.71 and 200), highlights, the approach acknowledges the importance of a 'natural setting' or 'real setting' for example a studio or workshop setting. The approach, as such is appropriate to the aims of this research.

Naturalistic inquiry was first adapted to art and design research by Katie Bunnell in 1998. Bunnell interpreted Robson's (1993, p.61) explanation of the central characteristics of naturalistic inquiry in relation to designer-maker practice. Bunnells (1998) interpretation of these characteristics is summarised in Figure 55.

Gray (2004, p.72), explains that Bunnell equates the notion of a natural setting with the studio or workshop environment and acknowledges the centrality of the researcher to research processes. This means that the researcher and the setting in which the research is conducted impact upon the research outcomes. The research outcomes are therefore context and researcher specific.

The following section expands on the specific methods used within this approach.
Figure 55: Characteristics of Naturalistic Inquiry as interpreted by Bunell for design research (Bunell 1998 and Gray and Malins 2004, p. 73).

- **Emergent Methodology:**
  Problem solving strategies emerge through immersion in the research problem and become focused through action. Reflection in and on action and structure improvisation are valuable to evolving the research strategy.

- **Natural Setting:**
  Research outcomes are seen as specific to the context in which the research is carried out and in relation to the validity of the study.

- **Tacit Knowledge:**
  Is implicit in the design process and is acknowledged as a legitimate element of design research.

- **Design Researcher:**
  Is central to the research

- **Idiographic Interpretation:**
  Research outcomes are interpreted in terms of the specifics of the case and presented as a unique study to the field of practice

- **Negotiated Outcomes:**
  Validity of findings are negotiated through peer review, exhibitions, workshops, seminars, published papers.

- **Special Criteria for Trustworthiness:**
  An analytical framework is developed as a method of explicitly interpreting research outcomes allowing research to be critically reviewed by others.
3.3 Methods

In her paper 'How to Investigate Textiles and Clothing – Some Methodological Viewpoints', Antilla (1995) emphasises the 'richness and complexity' of research in textiles (and clothing). Gray and Malins (2004, p.31 and p.72) also highlight that research issues and situations within design practice are often driven by a creative dynamic and involve real experiences and as such are complex. Both Antilla (1995, p.62) and Gray and Malins (2004, p.31) suggest that the use of two or more methods enable complex issues to be examined from different perspectives to enable the corroboration or refutation of ideas. Gray and Malins (2004, p.31) suggest that using multiple methods is 'more likely to yield a significant, critical holistic view than using a single method'.

Within this project two methods have been utilised:

- Reflective Design Practice;
- Focus Groups and Semi Structured Interviews.

The aim of this research to consider both industrial and craft perspectives in regard to design nonwovens has driven the approach to design within the research. The mode of practice developed is rooted in notions of craft and the focus groups and interviews aims allow the products to be evaluated within an industrial context.

These methods and the analytical framework used within the work are described below.

3.3.1 Reflective Practice

The method of design practice developed within this research is rooted in notions of reflective practice and a craft approach to design. As discussed above, design practice is considered as a legitimate research method as long as it is structured, systematically carried out and transparently documented. The sensitive adaptation of 'explicit protocols of conduct', as suggested by Gray and Malins (2004, p.18), will ensure that the work, whilst remaining emergent, is rigorous and clearly documented.

The notion of reflective practice and a craft approach are discussed below. The 'explicit rules' of practice employed are outlined below and the work conducted is summarised.

3.3.1.1 Reflective Design Practice

Reflective practice is a concept that has underpinned many of the developments within art and design research methodology. The concept was developed by Donald Schön (1983) as a way of reassessing the traditional view of professional knowledge. It provides a way of
understanding, making explicit and developing the knowledge gained through, and used in, professional activity (vii). It is based on the acknowledgment of professional knowledge as tacit and to do with 'know-how'. Schön (1983, p.56) described the processes of 'reflection in action' and 'reflection on action' as ways of articulating and extending this knowledge.

'Reflection in action' is about noticing the thought processes and intuitive actions that affect the choices made in and during practice. Schön (1983, p.55) suggested that through noticing how you have been doing what you're doing and based on this, changing the way you do it enables you to 'get a feel for it'. He noted that this 'feel' for something enables the practitioner to repeat the same thing that they did before that proved successful and also enables unsuccessful practice to be identified and improved or avoided. Through this process (and its articulation and documentation), Schön 'knowing-in action' can become 'knowledge-in action' (Schön, 1983, p.59).

Reflection-on-action is retrospective. Schön (1983, p.61) described that it involves thinking back over periods of practice and situations and exploring the understanding that the practitioner has brought to situations and the new understandings that have been gained. He explained that this is done both through 'ideal speculation' and as a deliberate effort to prepare (themselves) for future situations (ibid).

3.3.1.2 Craft Approach
Braodbent (2002, p.3) notes, Jones' (1970, p. 19-20) description of some of the key characteristics of craft methods in design. They include; the storing of product information in the product itself and through apprenticeship rather than through documentation; change in the product's form only occurs through experimentation not through drawing; the products are modified by trial and error over a long period of time. Jones highlights that craft is therefore a slow and costly process and is evolutionary by nature (1970, p.19-20 in Broadbent 2002, p. 3). In relation to this, Dormer (1994, p.10) discusses that if we had to rely on discovering ideas through craft... we might never have progressed as far as steam engines, let alone beyond'. He points to the need to use theoretical knowledge about the field of action in question as a springboard and as a means of improving practice. Within this research, practice is underpinned by the researcher's developing theoretical understanding of the field of nonwovens gained through literature reviews and discussions within industry specialists.

In a contemporary context, craft method is considered as an important element of designer maker practice and it often informs the development of prototype products. As discussed in Chapter 2, Gale and Kaur (2002, p.63) write that textile craft practice is 'commonly perceived as multi-media, exploring the inherent qualities of different textile materials' and that a 'craft approach to textiles is very much process-led; the actual pursuit of making by hand is of
paramount importance'. The nature of hand work enables personal interaction with the making process and an instinctive response to materials which is central to the design process within craft practice. It is acknowledged that craft practice results in craft (or tacit) knowledge which can be described as an understanding or feel for materials. Craft knowledge is perceived as valuable within the product development process with various modes of design practice.

The understanding of materials gained through craft practice, as Dormer (1997, p.157 in Yair 2001, p.63) highlights, relates to sensory perceptions of tactile and aesthetic qualities of materials rather than, as Pye (1968, p.45) notes, the measurable properties of materials such as conductivity, tensile strength and elasticity. Within this research design practice has been approached through craft method to enable a sensory understanding of the materials and processes in question to be developed and documented. The focus of the data collection and analysis is on evaluating the nonwoven processes employed in regard to the aesthetic qualities of the fabrics produced. In order to make this process transparent, ‘explicit protocols’ of practice were adhered to.

3.3.1.3 Explicit Protocols of Practice
The explicit protocols employed relate to Douglas and Moustaka’s interpretation of naturalistic inquiry as employed by (Bunnell, 1998);

<table>
<thead>
<tr>
<th>Stage</th>
<th>Process</th>
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<tbody>
<tr>
<td>Immersion</td>
<td>Idea generation/planning</td>
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<tr>
<td>Acquisition</td>
<td>Action/Response</td>
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<tr>
<td>Realisation</td>
<td>Observation/Analysis</td>
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These explicit rules were employed during the four distinct phases of practical research that are presented in the thesis. The four Stages are:

- Investigations into hand-based nonwoven fabric construction methods (Stage 1)
- Sampling using pilot scale nonwovens equipment (Stage 2)
- Investigations into decorative finishing processes (Stage 3)
- Realisation of design conclusions (Stage 4)
The aims, processes, materials, concepts and ideas used explored within these phases are described in detail in Chapters 4-7.

Idea generation and planning: This stage of the process draws on the researcher's tacit knowledge. In the initial stages of the research, this aspect is quite general and allows for immersion in the processes and technologies, a range of variables to be explored and for design strategies and ideas to emerge. As the work progresses (and as the researcher's tacit and implicit knowledge of processes, materials and technologies/tools develops) the aims become more specific allowing defined variables to be examined and specific data to be acquired.

The 'immersion' stage includes the selection, acquisition and preparation of materials, the development of visual research, collation of theoretical information and preliminary fabric sampling.

The tools used for immersion are summarized as follows:

- Collation of inspirational visual material including drawing;
- Note taking and mind maps in sketch books;
- Collation of fibres and fabrics;
- Preliminary sampling;
- Developing written summaries;

Action/response: This stage involves the practical exploration of ideas through a series of process investigation. These investigations revolve around making and manipulating textile samples. Investigations are based upon the previous stage to ensure continuity and a systematic approach. The need, however, for the researcher to respond intuitively to each investigation through reflection in action is acknowledged. This allows a creative dynamic through reflection in action to evolve rather than realising controlled conditions.

In order to achieve continuity in terms of the acquisition of technical and reflective data, structured documentation sheets are employed. The format of these sheets evolves as familiarity with the technology increases and experimentation becomes more specific. Photography is also used as a documentary tool and contextual information is recorded through reflection in and on the experimental periods.
Chapter 3 Methodology

The data acquisition tools used in this stage of the process are summarised as follows:

- Fabric making;
- Structured documentation sheets;
- Note taking;
- Photography;
- Developing written summaries;

**Observation:** Observation as a central element of all stages is realised through reflection in the planning, action and analysis stages. The acknowledgement of the researcher as central to the research process is crucial. Gray and Malins (p. 106), suggest that in some senses, the researcher becomes a 'participant-observer' within the research process. Observations were recorded during each stage of practice using:

- Sketchbook notation
- Structured documentation sheets and tables

**Analysis:** This stage of the process enables the realisation of new knowledge and the identification of further experimental ideas. The approach to analysis is qualitative, based on three key stages; data reduction, data display and drawing conclusions/verification. To aid the analytical process Victor Papanek’s ‘Function Complex’ (1985, p.7), as discussed below, is employed as an analytical framework. This framework and the protocols employed in the analytical processes are discussed below.

3.3.2 Focus Groups and Interviews

Within the development of qualitative research for design, Christopher Ireland (2003, p.23-24) discusses focus groups as one of the first methods to gain attention. First used as a method of gauging listeners' responses to radio shows in 1940, focus groups have become widely used by market researchers within social science research (Langford and McDonagh, 2003 p.2-3). Focus groups involve facilitating groups of people to engage in a planned discussion on the topic of research/interest (Langford and McDonagh, 2003, p.15). They sometimes involve creative or thinking activities alongside discussion (ibid, p. 2).

The value of focus groups is seen as lying in their potential to unearth information that may otherwise have remained undiscovered using more formal research methods (ibid). Langford and McDonagh (2003, p.15) suggest that this is in part due to the 'synergistic effect of group discussions. This enables participants to build on the ideas and responses to others. Ireland
highlights that within design research, focus groups enable peoples reactions, feelings and preferences in relation to specific designs to be gauged (2003, p.24). Disadvantages include the negative influence a dominant group member can have on a group through monopolising discussion (Langford and McDonagh, 2003, p.4). Alongside this, the content and quality of discussion can not always be predicted due to the nature of group dynamics.

3.3.2.1 Focus Groups and Interviews in Design Research
Within design research, Ireland (2003, p.23-24) describes their development as a method within design research from being ‘talk only environments’ to experimental contexts for engaging with users. He notes that originally used for any purpose, focus groups are now recommend as tools to generate design ideas and/or expand understanding. Langford and McDonagh (2003 p.7) list further purposes of focus groups within design research including:

- Understanding users, tasks and behaviours;
- Identifying problems and establishing user and task needs;
- Establishing frameworks for further research;
- Evaluating existing or proposed designs;
- Generating new design concepts;
- Influencing and supporting decision making.

They suggest that the use of focus groups is rarely limited to only one of these applications as there is considerable overlap between them (Langford and McDonagh, 2003, p.14).

Ireland (2003, p.25) highlights one-one interviews as a qualitative method that can be used for similar purposes as focus groups. Although not having the ‘synergistic dynamic’ of focus groups, Ireland notes that they too, can be used to discover people’s feelings, thoughts and opinions about a design. John Chris Jones (1992, p.214) discusses the use of interviews within design as a tool with which to explore design situations. He sees them as methods to elicit information that is known only to the users of a product or system. Gray and Malins (2003, p.118) also describe the advantages of interviews as their potential to find out people’s values, preferences and feelings and to encourage in depth response.

Within this research, focus groups and interviews are applied as a means of developing negotiated outcomes and as a form of peer review through evaluating fabric designs and the transferability of design ideas, generating new design concepts and establishing frameworks for further research. They are intended to further establish the ‘trustworthiness’ and validity of the research. The thesis presents four distinct sets of groups and interviews that were conducted at various stages of the work:
Chapter 3 Methodology

- Focus groups with textile design semi-professionals;
- Focus groups with textile design professionals;
- One-one interviews with product design professionals;
- One-one interviews with nonwoven manufacturers.

Specific tools were used to plan, conduct, document and analyse each set of groups/interviews including:

- Purposive sampling
- The development of moderators guides
- Dot voting
- Feedback forms
- Transcription of discussions
- Category analysis

Each of these methods are discussed in detail in Chapter 8. For continuity with the practical aspect of the research, the approach to analysis is qualitative, based on three key stages; data reduction, data display and drawing conclusions/verification. To aid the analytical process Victor Papanek's 'Function Complex' (1984, p.7), as discussed below, is employed as an analytical framework. This framework and the protocols employed in the analytical processes are discussed below.

3.3.3 Analytical Framework
As referred to in the previous section, Robson explains that there are no pre-determined sets of conventions or rules for qualitative analysis (2002, p.456). However, he points out that a number of ways of systematically dealing with qualitative data have been developed (ibid). Gray and Malins (2004, p.156), affirm the necessity for a systematic approach to analysis within (art and) design research by highlighting the need for analytical frameworks and criteria. It is highlighted, however, that although systematic, qualitative analysis is described as 'playful, imaginative, flexible and reflexive' and as 'intellectual craftsmanship that is playful but methodically and intellectually confident' (Coffey and Atkinson in Gray and Malins, 2004 p.156 and p.132).

Within this research, Miles and Hubberman's (1994) concept of three concurrent flows of activity in analysis and Papanek's function model have been used to develop an analytical framework.
3.3.3.1 Outline of Analytical Activities

Robson (1993, p.456) describes that an important element of qualitative analysis is that it is ongoing and that new data is continually collected. Gray and Malins (Gray and Malins, 2004 p.144) draw on Miles and Hubberman's (1994) concept of three concurrent flows of activity in analysis which considers three activities which are continual throughout the research process:

- Data reduction
- Data display
- Drawing conclusions/Verification

Within the practical aspects of the research data reduction involves the grouping and organising of fabric samples and contextual information. Summary texts are also developed after each stage of practice. Grouping and organising is based on the specific aims and objectives of each stage of practice and individual process investigations and in relation to the research questions. At this stage, data is displayed through the physical organisation of fabrics and documentation, the development of data bases of technical information and the creation of flow charts incorporating contextual and technical information, observations and reflections. Having grouped and displayed the data, the conclusions are drawn through the development of written texts and by drawing theoretical information. Interviews with nonwoven manufacturers and the wider design community alongside peer based focus groups, as discussed below, are used as methods of 'validating' and testing the conclusions drawn.

In the focus groups and interviews themselves, data, display and analysis were also employed. Data reduction involved developing themes and categories relating to each discussion. This information was summarised and displayed in table format. Conclusions were drawn by documenting the frequency of those themes in order to assess their importance. The conclusions were developed by exploring them within the framework of Papanek’s Function Complex, as described below, and by drawing on some of the theoretical discussions outlined in Chapter 2.

3.3.3.2 Papanek’s Function Model as an Analytical Tool

Anttila (1996, p. 52–53) proposes the application of Victor Papanek's 'Function Complex' to investigating clothing and textiles artefacts. Papanek's (1985, p.7) Function Complex model defines six interrelating 'aspects' of an artefact's purpose; method, use, telesis, association, aesthetics and need. Papanek (1985 p.23) proposes that every artefact operates within all six functions but implies that particular functions are prioritized dependent upon the artefacts purpose and context. He describes these functions as evaluative criteria and in doing so
emphasizes the need to acknowledge the soft/hard, feeling/thinking and intuitive/intellectual elements within (Papanek, 1985, p.7). Each of the functions are summarised in Figure 56.

Within the practice element of this research the 'method' and 'aesthetic' aspects are evaluated in regard to the fabrics in question. In regard to the focus groups and interviews, the aspects of 'method', 'aesthetic', 'use' and 'association' have been considered. These aspects have been used as headings to develop analysis and draw conclusions.

**Use:** Considers the intended primary use of the artefact. Does it work? What are the wider consequences of the use? Can be evaluated from various standpoints.

**Method:** Considers the interaction of tools materials and processes. An honest use of materials is required. Aesthetic is often determined by the method. Elegant solutions are possible when materials, processes and tools interact creatively.

**Telesis:** Considers the content of an artefact that reflects the times and conditions that have given rise to it. An artefact must fit in with the general socioeconomic order in which it is to operate.

**Aesthetics:** No ready yardstick for analysis. Design tool of primary importance that shapes forms and colours into entities that move us and are meaningful. Often determined by personal expression and to do with what we like and dislike.

**Need:** Considers the genuine needs of man – economic, psychological, technological, spiritual, social and intellectual. Asks what is the functional need for a particular artefact?

**Association:** Considers how psychological conditioning, past and present experiences predispose us to valuing or holding antipathy towards artefacts. Redesigning this aspect of an artefact can lead to new market areas.

**Figure 56:** Function Complex Model, Victor Papanek 1985, p. 7-24.
3.4 Summary

This chapter has outlined the methodological approach taken and the methods used within this research. The chapter distinguishes between scientific and design approaches to studying textiles and in doing so situates this research in the latter.

In summary the methodological approach is qualitative and naturalistic. The chapter discusses that the main methods used within this approach are reflective practice, focus groups and interviews. The method of reflective practice employed is contextualised within designer-maker practice, is rooted in notions of craft method and applies explicit protocols. The focus groups and interviews employed draw on established methods and tools used within design research. The analytical approach employed utilises Papanek's function complex model as an analytical framework and involves continual data reduction, data display and drawing conclusions.
4.1 Introduction

In Chapter 2, three textile production contexts were discussed, namely industrial, craft and class production. It was discussed that in order to achieve ‘class production’, in which design and innovation are central to production, a balance needs to be retained between a craft approach to manufacture and a consideration of the opportunities and limitations of industrial manufacture. The importance of craft knowledge within design was outlined and in particular the importance of personal interaction with materials and processes to develop a ‘feel for materials’. Peter Dormer’s (1997, p.168-175) identification of the ability of woven textile production to span craft and industrial production contexts successfully was highlighted. Dormer noted that this fluidity of practice between craft and industry within woven textiles production was due to the existence of a common technical language and enabled innovation to be achieved. The discussion in Chapter 2 brought into question the existence of a fluid practice and common language between production contexts within the sphere of nonwovens.

From this point, a series of practical investigations into hand-based methods of nonwoven production were conducted to enable the researcher to begin to develop a ‘hands-on’ understanding of the basic principles of nonwoven construction. It was also intended that the notion of ‘fluid practice’ between nonwoven production contexts and, subsequently, the potential and limitations of working as a designer within this field could begin to be explored.

4.1.1 Aims and Approach

As established in Chapter 2, needle-punching has been the most explored nonwoven process in terms of design with much of the work focusing on concepts of fibre transfer and appliqué like techniques. The resulting work often resembles felt. It was; therefore, proposed, that initial investigations should focus on alternative nonwoven processes. Using the ‘mapping’ exercise outlined in Chapter 2, four nonwoven technologies that could be replicated by hand-based technologies were identified and investigations into each were conducted. These were:

- web formation technologies;
- chemical bonding technologies based on printing processes;
- chemical bonding technologies based on ‘spray’ processes; and
- thermal bonding technologies that utilise heat and pressure.

The aim of each investigation was to create stable nonwovens. The term ‘stable’, was used within the investigation to describe a fabric that remained intact when handled. This was assessed subjectively by the researcher during the making process.
Chapter 4  Practical Research Stage 1

This Chapter covers the following areas for each investigation:

- materials used;
- sampling methods and equipment;
- observations and reflective analysis of the processes and resulting fabrics.

A number of the sampling methods described are based on well known and documented textile processes. However, it was considered important to document them within the context of this research.

Each fabric sample produced is documented in Appendix 1. The details given document the making parameters in order to enable observations to be made. They provide a starting point for reproducing the fabrics that were made. When specific samples are referred to in the text, their sample number is quoted in brackets.

4.2 Web Formation Investigation

Industrially, fibre preparation for nonwovens is achieved by ‘opening’, ‘dosing’ and ‘blending’ processes. The opening process involves the breaking up of large bales of fibre using spiked rollers (Leifeld, 2003, p.142). Leifeld (2003, p.143) explains that the dosing process sorts the fibres into weighed units and that the units of fibre are then mixed together in the blending process. In each of these processes, Leifeld (2003, p.143), notes that precise calculations are used because the precision and quality of the blend impacts considerably on the quality of the final fabric. In hand-based textile production, similar processes, such as teasing and carding, are used to prepare fibres for spinning and felting. The fibre preparation and web formation techniques developed within these investigations drew on the traditional use of these processes. The processes are described in this chapter as adapted for use in these investigations.

4.2.1 Materials

Nonwoven webs are made either directly from staple fibres or from continuous fibre filaments extruded from molten polymer (Albrecht et al, 2003, p.140). Owing to the type of technology required and accessibility to it, extrusion processes were not considered as a viable area of investigation within this stage of the research. The investigations therefore focus on the use of staple fibres to create nonwoven webs.

Virtually all kinds of fibres can be used to make nonwovens. From an industrial perspective, Albrecht (2003, p.15) suggests that the main factors influencing the choice of fibre are the desired properties of the end fabric and the level of cost effectiveness required in production.
Jirsák and Wadsworth (1999, p.23) also highlight the need to consider the processability of the fibre in relation to the production technologies being used. The properties of the raw fibre used, for example the dimensions, performance properties and aesthetic characteristics etc, impact upon the properties of the final fabric. Albrecht (2003, p.13) notes that in nonwoven production, the choice of fibre impacts more on the characteristics of the resulting fabric than is the case in conventional textile production.

4.2.1.1 Fibre Selection

In Chapter 2, it was identified that the range of fibres explored by designers working with industrial nonwoven technologies, particularly thermal bonding processes, appears to have been relatively limited. Therefore, in selecting fibres for this research, the aim was to source as diverse a range of fibres as possible, particularly in terms of aesthetic characteristics. Within industry, although almost any fibre type can be used to make a nonwoven over 90% of industrially manufactured nonwovens are made from synthetic fibres and only 3% from speciality fibres, which include natural fibres (Wilson, 2007, p. 9). It is proposed that using a range of natural fibres, including those that are often perceived as luxury fibres as well as synthetics is one means of developing 'high-end' nonwoven fabrics.

As noted above, the processability of a fibre in relation to the technology is often a key consideration when choosing raw materials for nonwoven production. Whilst such processability was a factor in the selection of fibres for this research, it was not the main influencing factor, as it was felt that a trial and error approach to using various fibres would be more beneficial in light of the aims of the investigations.

Table 1 lists the fibres selected at this stage of the research and gives details of their aesthetic and performance qualities.
<table>
<thead>
<tr>
<th>Fibre Name</th>
<th>Fibre Type</th>
<th>Fibre Form</th>
<th>Visual and Tactile Qualities</th>
<th>Properties (dependent on fibre count and length)</th>
<th>Supplier/Trade Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscose</td>
<td>Man-made Man-made Regenerated cellulose</td>
<td>Staple Fibres</td>
<td>Looks and feels like Cotton Wool Bright white in colour</td>
<td>Adequate fibre strength Weak and extensible when wet Bad resistance to abrasion</td>
<td>Lenzing</td>
</tr>
<tr>
<td>Polyester</td>
<td>Man-made Man-made Synthetic Polymer</td>
<td>Staple fibres</td>
<td>Soft but with a plastic like handle White in colour Fibre crimp visible</td>
<td>Crisp handle Good crease recovery Good resistance to extension</td>
<td>Terital™</td>
</tr>
<tr>
<td>Tri-lobal Nylon 1</td>
<td>Man-made Man-made Synthetic Polymer</td>
<td>Staple fibre</td>
<td>Coarse handle Iridescent White in colour Defined long lengths of fibre</td>
<td>High tensile strength Excellent resistance to abrasion</td>
<td>Wingham Wool Works</td>
</tr>
<tr>
<td>Tri-lobal Nylon 2</td>
<td>Man-Made Man-Made Synthetic Polymer</td>
<td>Staple fibres</td>
<td>Coarse handle Iridescent Fibres matted together</td>
<td>High tensile strength Excellent resistance to abrasion</td>
<td>Wingham Wool Works</td>
</tr>
<tr>
<td>Tencel® (viscose)</td>
<td>Man-made Man-made Regenerated cellulose</td>
<td>Staple fibres</td>
<td>Soft cotton like fibre White in colour</td>
<td>Cotton like properties High tenacity</td>
<td>Acordis (now Lenzing)</td>
</tr>
<tr>
<td>Ramie</td>
<td>Natural Natural Cellulosic Cellulosic Vegetable Origin</td>
<td>Sliver of filaments</td>
<td>Very lustrous Very soft, almost silky Long defined lengths of fibre</td>
<td>Natural lustre Durable Launderers easily Dries quickly</td>
<td>Hand Weavers Studio</td>
</tr>
<tr>
<td>Wool/linen Mix</td>
<td>Natural Natural Animal/Vegetable Origin</td>
<td>Carded fleece</td>
<td>Soft Textured appearance (small neps visible) Cream/off white in colour</td>
<td>Soft full handle Shrinks when washed</td>
<td>Wingham Wool Works</td>
</tr>
<tr>
<td>Silk</td>
<td>Natural Natural Animal Origin</td>
<td>Sliver of filaments</td>
<td>Very lustrous Cream in colour Very soft Long defined lengths of fibre</td>
<td>Excellent draping qualities High tensile strength Reduction in strength when wet</td>
<td>Fibre Crafts</td>
</tr>
<tr>
<td>Polyester Lux</td>
<td>Man-made Man-made Synthetic Polymer</td>
<td>Staple fibres</td>
<td>High loft Very soft Bouncy, curly</td>
<td>As polyester</td>
<td>Hand Weavers Studio</td>
</tr>
</tbody>
</table>

Table 1: Fibre Information. The Information in table is based on discussions in Taylor (1997, p.33) and Gordon Cook (1984) and personal observations.
4.2.2 Sampling Method

This section describes the methods and sampling procedures used within the investigation. The fibre preparation and web formation methods used will be outlined.

4.2.2.1 Fibre Preparation

The fibres were prepared for web formation using the teasing and carding processes.

**Teasing**

Teasing is a process that involves the gentle pulling apart (opening) of clumps of fibre by hand to de-mat, de-tangle and clean them. In this investigation this process was conducted where required.

**Hand Carding**

Following teasing, the fibres were further opened and de-tangled using a hand carding process. Hand carding is routinely used in a range of traditional textile processes such as spinning and felting to prepare fibres for further processing. Hand cards comprise of two flat surfaces covered uniformly in metal wires (or 'teeth'). The hand carding procedure used in this investigation is illustrated in Figures 57–60.

Small amounts of fibre were spread over the surface of one card (Figure 57). The other card was drawn in opposition across its surface a number of times (Figures 58 and 59). The fibre was opened through this action and distributed over both cards in a parallel manner. By drawing the cards in the same direction, the fibres were transferred to one card only and removed by hand (Figure 60).

**Figure 57:** Placing Fibres onto the card

**Figure 58:** Drawing cards in opposition to open and align fibres
Some fibres required more attention at the fibre preparation stage than others. Fibres that were particularly matted required more opening and so the procedure was repeated a number of times. Other fibres could be effectively opened by hand and did not need to be opened using hand cards.

Only one type of fibre was used in each web, for the initial investigations to gain an understanding of the fibre's behaviour in the making process and the characteristics of the resulting fabric. In later investigations, where fibre blends of two or more fibres were required, each fibre was teased and opened as described above. The required amounts of each fibre were then weighed, distributed proportionally across the surface of the card and carded to blend the fibres in the required ratio. This was done as uniformly as possible.

As discussed below, fibres with a longer fibre such as the silk and ramie proved difficult to process at the web-formation stage. To overcome this, in some instances, these fibres were cut into shorter lengths during the fibre preparation stage to enable more effective web formation.

4.2.2.2 Web Formation
Following fibre preparation, webs were made using a Drum Carder.

Drum Carding
As described in Chapter 2, drum-carders comprise of a series of drums covered in metal wires or teeth (carding cloth) that comb staple fibres into a parallel fashion resulting in a web or batt of fibre. Jirsák and Wadsworth (1999, p.55) suggest that in industrial carding processes, the type of carding equipment used is said to impact upon the quality of the
resulting fabric. They note, however, that there are no clear relationships between the fibre material being processed and the kind of carding cloth used and that the choice of cloth is usually made following discussions between the machinery and nonwoven manufacturers, and is based on achieving optimum quality and productivity (Jirsák and Wadsworth, 1999, p.55). In hand-based felting and spinning processes that utilise drum carding, the carding cloth size is considered in relation to the type of fibre being processed. The cloth is measured in the number of teeth (or points) per square inch, 22 points being the norm for use with coarse fibres and up to 72 points for finer fibres.

The drum carder used in these investigations was a Louet model comprising of one large drum and one small drum each covered with 46 point carding cloth. This model was selected to enable a range of fibres to be carded effectively.

The carding procedure used in these investigations is illustrated in Figures 61–66 on the next page. Small amounts of fibre were placed in front of the small drum (Figure 61) and were fed into the carder by turning the crank in a clockwise direction (Figure 62). The fibres were taken up by the small drum and, where the two drums meet, the fibres were transferred onto the large drum. As fibres were added and the crank was turned, forming a web on the surface of the large drum (Figure 63). Fibres that built up on the small drum were then removed by drawing a doffer brush in opposition against the surface of the drum (Figure 64). Once the large drum was full or the web had reached its desired thickness and evenness, it was removed by inserting the doffer pin under its width. The web was then lifted (figure 65) enabling it to be cut and gently taken off the drum, in a single layer, by turning the crank in an anticlockwise direction (Figure 66).
Chapter 4  Practical Research Stage 1

Fibre Quantity
Initially, various quantities of fibre ranging from 10g to 30g were fed into the carder to observe the quality of web achieved by each quantity. Between 10g and 15g of fibre was identified as the optimum weight to consistently create a relatively stable and even web. This quantity was therefore used in subsequent sampling.

Layering
Once each web had been removed from the carder, samples of various weights and densities were created by layering webs on top of each other by hand. As described in Chapter 2 (ref), different mechanisms are used in industrial production to determine the position of the fibres in the resulting fabric. In this investigation, webs were layered in a parallel fashion (i.e. all fibres moving in the same direction). Heavier samples were made by building up layers and, conversely lighter webs made by pealing off thin layers of fibre from the original web (where possible). The details of how each web was made are set out in Table 1 in Appendix 1.

Figure 63 and 64: Creating the web and removing fibre from the small roller using the doffer brush.

Figure 65 and 66: Inserting the doffer pin and removing the web.
4.2.3 Analysis: Observations and Reflections

The observations and reflections made during the fibre preparation and web formation processes conducted are discussed in this section.

4.2.3.1 Fibre Preparation

The extent to which the fibres were opened affected the surface qualities of the resulting web and subsequent fabric. Opening fibres to a lesser extent generally resulted in fabrics that were uneven in terms of density and surface quality and in which defined lengths or clumps of fibre were visible. This gave a textured appearance but the structural integrity was inconsistent (H21). Opening fibres to a greater extent before web forming resulted in fabrics with a more even surface quality and relatively consistent structural integrity (H11). This is illustrated in Figures 67 and 68.

In terms of the behaviour of each fibre, longer fibres proved difficult to process in the drum card. To overcome this, in some instances long fibres such as silk and ramie were cut into shorter lengths. This enabled the fibres to be carded more effectively. Changing the characteristics of the fibre in this way changed the quality of the resulting fabric. Shorter, coarser fibres with more crimp, such as the polyester lux and wool required no preparation, as they were successfully drum carded in their original state.

4.2.3.2 Web Formation

As noted previously, the quality and characteristics of each web was determined by the characteristics of the fibre used and how it had been prepared.

As shown in Figure 69 (H8), the short, matted, soft and textured quality of the wool/linen mix fibres resulted in a web and subsequent fabrics with a matted visual quality, soft handle and
good stability. This fibre was relatively easy to process in the drum card and, therefore, resulted in a comparatively consistent web.

The ramie fibre, which was soft, smooth and long, resulted in webs (and subsequent fabrics) in which individual lengths of fibre were visible, as illustrated in Figures 70 (H15). This created visual detail. Owing to the length of this fibre, however, they were difficult to process and resulted in inconsistent webs (and subsequent fabrics) with a comparatively lower level of structural integrity.

The polyester lux fibres were carded effectively and the crimped, springy nature of the fibres resulted in an even and consistent web (and subsequent fabrics) that held together well. This is shown in Figure 71 (H24). The soft springy nature of this fibre is reflected in the web produced.

The size of the carding cloth impacted on the structure and visual appearance of the viscose fibre by causing the fibre to form loops around the carding wires. This is evident in the fabric produced, as shown in Figure 72 (H12).

The crimped quality of the polyester fibre was evident in the resulting web because it was not fully opened in the fibre preparation stage. This is illustrated in Figure 73 (H16).

The coarse iridescent of the tri-lobal nylon is reflected in visual and tactile qualities shown in Figure 74(H10).
4.2.3.3 Summary

The fibre preparation and web formation methods used were effective in making webs that had enough integrity to progress to the bonding stage. The quality of the webs produced, however, was generally uneven and inconsistent. The uniformity of most of the webs varied within each sample creating a patchy and textured appearance. The range of surface qualities achievable was as wide as the range of fibre types available. The qualities and properties of the fibre and their processability within the drum card determined the appearance, handle and stability of webs produced. The investigation enabled an understanding to be gained of how each fibre responded to the carding process and the visual and tactile qualities of a basic web made from each of these fibres.
4.3 Chemical Bonding Investigation: Printbonding

As outlined in Chapter 2, a range of chemical bonding methods are used in industry to consolidate webs. Chemical binders are usually in the form of polymer dispersions (latex) or solutions (EDANA (2), 2006). There are generally two stages in chemical bonding; firstly the application of the substance and secondly the triggering of bonding by heat (Ehrler and Schilde, 2003, p.369). A number of methods are used to apply binders and trigger bonding. Two methods of chemical bonding were explored in this research - print bonding and spray bonding.

In industrial manufacture, print bonding is used when specific formations of binder within the web are required. The process allows specific areas of the web to be bonded and others to be free from binder (EDANA (2), 2006). As outlined in Chapter 2, patterned rollers or rotary screens are often used to apply binding solutions to webs.

In this investigation traditional hand-based screen-printing methods were explored as a means of applying a chemical bonding solution to the webs made in the previous investigation.

4.3.1 Materials

4.3.1.1 Fibre Webs

The webs made in the previous investigation were made of various staple and filament fibres as documented in Table 1. Each web is detailed and numbered in the Appendix 1 Table 1.

4.3.1.2 Binding Fluid

Binder fluids are not specific to certain types of web or even exclusive to nonwovens. They are often used within nonwoven construction in the same or in similar formulas as used within the areas of textile finishing, printing, paper and plastics industries (Ehrler, 2003, p.120). A number of binding fluids used in textile printing were considered for the print bonding investigations discussed in this chapter, as it was felt that these materials would be suitable for the chosen method of application - printing. A binder called Ecotex was selected owing to the availability of the technology needed to fix it in the fabric and its permanence once fixed. Ecotex is usually used for printing acrylic pigment onto textiles. It is fixed using dry heat and does not require a washing off process. Unlike other binders used in printing, it remains in the fabric after washing (to hold the pigment on the surface of the textile) rather than acting as a temporary binder holding dye in place until the dye is fixed onto the textile.
4.3.2. Sampling Method

In screen-printing, the fabric to be printed is usually ironed flat to the printing table to give a smooth, flat surface on which to print. In their un-bonded state, the webs were quite voluminous and needed to be compressed to enable printing to take place. The webs were not stable enough to be ironed (the movement of the ironing process caused the webs to distort) and so were prepared for printing using a heat transfer press. Each web was placed between release papers and pressed at a low temperature. This compressed and flattened the webs to ensure minimal disruption to their surface.

The webs were then gently tensioned by taping them at each corner to the printing table (this was intended to minimise the movement of the web during printing). The binder was applied by forcing the solution through a silk printing screen using a squeegee. Initially a simple grid design was exposed onto the screen so to avoid the binder being applied to the entire surface of the web. Having applied the binder, the webs were left to dry naturally and the binder ‘fixed’ by applying dry heat using the heat transfer press. Each web was placed between two sheets of release paper and pressed at 180°C for 20 seconds.

As discussed in the analysis below, this process proved inconsistent due to the fragility of the webs before printing. A number of measures were, therefore, taken to try to stabilise the webs before and during printing. Some webs were sprayed with starch to stiffen and therefore stabilise the fibres prior to printing. Others were dampened with water to reduce static or a layer of stiff netting incorporated between the web and the screen during printing to stop the web sticking to the surface of the screen (an unexposed screen was used in these instances). The details of the processes used to apply binder to each web are given in Table 1 in Appendix 1.

4.3.3 Analysis: Observations and Reflections

4.3.3.1 The Screen Printing Process

As highlighted above, printing the carded webs with a binding solution proved a difficult and inconsistent process. The webs were too fragile to survive the process fully intact. It was difficult to place them under sufficient tension and following printing, as the screen was lifted from the table, the top layer of the fibres stuck to its surface distorting the web. The top layer of the webs could, however, be carefully retrieved and, though much thinner and lighter than the original webs, resulted in structurally stable fabric samples.

4.3.3.2 Introducing Starch and Water

To improve this process a number of the webs were sprayed with starch before printing (H5, H16). Using starch stiffened and dampened down the webs and created a smoother surface
on which to print and enabled the webs to be tensioned more easily. This improved the printing process but the webs still had to be handled with much care. When fixed and dried the resulting fabrics were stiff and strong. When the starch was washed out, the fabrics retained some strength but became much softer. Spraying a little water onto the surface of the webs, seemed to reduce the amount of static present in the printing process and compacted the fibres. This created a more suitable surface on which to print (H12, H14). Both the starch and the water improved the consistency of the process and enabled larger sections of the webs to be retrieved as fabric samples.

4.3.3.3 Incorporating a Layer of Netting
Incorporating a layer of stiff netting between the web and screen before printing stopped the webs from sticking to the screen. This enabled more of the original web to be successfully bonded and resulted in greater fabric stability. An unexposed screen was used which meant that more binder was transferred to the web. This resulted in fabrics with a stiffer handle (sample H15). The texture of the net was visible on these samples.

As is the case in industrial print bonding processes, the printing process discussed here only applied binder to the surface layers of the web. The fact that only one side of the web was bonded created an interesting contrast in terms of handle between the front and reverse of the fabric (H8, H15). In areas of the webs where binder was successfully applied and bonded, a smooth, flat/compressed surface was created. The reverse side of the webs retained their original softness but were comparatively unstable with loose fibres on their surface. Although structurally unsound, this did create an interesting contrast of surfaces and fabric handle which could be manipulated to a designer’s advantage for a suitable end-use. In contrast, when reprinted on the reverse side the handle is uniform and fabric stability, from a subjective perspective, is increased (H9).

4.3.3.4 Summary
As only the top layer of the web was successfully bonded, this process is limited in terms of the weight of fabric that can be produced. It is possible to create lightweight translucent webs but it would seem that heavier denser webs cannot be successfully produced using this method. In regard to industrial print bonding these observations are already known. In regard to the hand-based methods discussed in this section, further work into the impact of pattern and different types and concentrations of adhesive on fabric handle and strength may be beneficial.
4.4 Chemical Bonding Investigation: Spraybonding

Spraybonding was explored as an alternative to printing as a means of applying a chemical binder using hand-based or low technology equipment. As outlined in Chapter 2, spray bonding, is achieved through the application of binding solution using high-pressure spray guns. This investigation explored hand-based means of applying a binder solution through spraying.

4.4.1 Materials

4.4.1.1
The webs made in the previous investigation comprised of various staple and filament fibres as documented in Table 1. Each web is detailed and numbered in Table 2 in Appendix 1.

4.4.1.2
Ecotex was again used as the binder but was watered down to enable it to be sprayed effectively. 10% Ecotex and 90% water were used in the spray solution.

4.4.2 Sampling Method

Within this investigation, a basic spray bottle was used to apply the binder solution. The bottle used was a plastic pump action bottle with an adjustable nozzle to enable the intensity of spray to be adjusted (this type of bottle can be commonly brought at hardware/gardening stores). The webs were sprayed with a fine mist of solution on one or both sides. They were then left to dry. To fix the binder, each web was placed between two sheets of release paper and pressed at 180°C for 20 seconds. Table 2 in Appendix 1 details the process used on each web.

4.4.3 Analysis: Observations and Reflections

4.4.3.1 The Spraying Process

Using a basic spray bottle to apply a binding solution proved an effective means of bonding carded webs made from a range of fibres.

The resulting fabric samples differed from those that had been printed with a binding solution. Although the handle of the webs was stiffened to some extent through the spraying process, the effect was more subtle and the fabrics retained more of the volume of the original webs. The samples were, however, a little weaker. This was probably due to the weaker concentration of binder solution applied, and the absence of the compression process to prepare the webs and the impact applied to the web during printing.
The resulting fabrics were similar to those that had been printed with a binding solution in that contrasting surfaces within a single sample were created. When sprayed on one side only, there was a contrast in terms of the handle and extent of bonding between the front and the reverse of the fabric (H22, H23, and H24). When sprayed on both sides it seemed that a greater bond was achieved (H25, H26, and H27).

As is documented in current literature, although when spraying the binder, as opposed to printing it, it seemed to penetrate further into the web, it was evident that the webs were not fully bonded.

4.4.3.2 Summary

The spraying process proved an effective means of bonding hand-carded webs. It was possible to create a range of fabric weights using this method with various surface qualities and handles dependent upon the fibre used, quantity of binder applied and its location in the web. It is suggested that the structural integrity of the fabrics produced could be improved by using a binder with a greater concentration of binding solution or a stronger binding agent. This may, however, impact adversely on the handle of the resulting fabrics.

4.5 Thermal Bonding Investigation

Thermal bonding is achieved in industry using a number of technologies and processes. One of the main methods used is the incorporation of thermoplastic binder fibres into the matrix of the web. The fibres are incorporated into the web at the fibre blending stage. When the web has been made, the binder fibres are activated by heat and or pressure to create a bonded fabric.

Spindler (2003 p. 129) highlights that there is no need for additional processing equipment beyond that needed to produce carded webs to incorporate binder fibres into those webs. Because of this, it was felt that a hand-based process of thermal bonding using binder fibres could be developed using the fibre preparation and web forming techniques established in the Web Formation Investigation (outlined in section 4.2).

As discussed in Chapter 2, Bartlett’s (1997) research into the use bi-component thermoplastic binder fibres to create stable fashion fabrics identifies the use of a heat transfer press as a successful means of bonding thermoplastic webs. Taking Bartlett’s results into account and due to the availability of a heat transfer press, it was felt that this method would be suitable for use and would build on established knowledge. This research builds on Bartlett’s by incorporating thermal bonding methods into a hand-based mode of producing nonwovens and
Chapter 4 Practical Research Stage I

by beginning to explore the combination of thermoplastic binder fibres with a wide range of natural and synthetic fibres

4.5.1 Materials

4.5.1.1 Fibres

Six of the fibres documented in Table I were selected for use. The selection was intended to represent a broad range of fibre qualities in terms of aesthetics. Within this investigation these fibres are referred to as 'main fibres' to differentiate them from the binder fibre.

4.5.1.2 Binding Fibre

Binder fibres are made from thermoplastic polymers and can be described as hot-melt adhesive fibres (Spindler, 2003, p. 129). They are made up of 100% thermoplastic polymers, described as mono-component fibres or bi-component fibres. Bi-component fibres are made of two different polymers or one polymer at two molecular weights, with different melting points. As discussed in Chapter 2, to consolidate nonwoven webs, binder fibres are included in the main matrix of the web. Their basic function in the web can be described as follows.

When subjected to heat and pressure the binder fibres liquefy, surround the main fibres and mechanically anchor them inside the web as they cool and dry (Spindler, 2003, p. 134). Bi-component fibres differ from mono-component fibres in that they are constructed with a core component and a sheath component. The sheath component has a lower melting temperature to that of the core component. When subjected to the correct temperature the sheath component liquefies enabling bonding to take place. The core component remains in its original state providing strength in the resulting fabric.

A number of thermoplastic bonding fibres were considered for the thermal bonding investigation. A polyester bi-component fibre, Wellbond M1440, was kindly supplied by Wellman International.

This fibre begins to liquefy at around 90°C. For industrial purposes, the fibre is bonded at temperatures between 130°C - 190°C in order for strong bonds to be achieved. The higher the temperature the more the fibre liquefies and runs, creating more bonded points within the web resulting in a stronger more plastic like fabric. However, if the temperature is too high, the fibre will run to the bottom of the web creating an uneven level of bonding within the fabric, which results in a weak fabric. The details of Wellbond M1440 fibre are given in Table 2.
### Table 2: Binder Fibre Information

<table>
<thead>
<tr>
<th>Fibre Name</th>
<th>Fibre Type</th>
<th>Fibre Form</th>
<th>Visual and Tactile Qualities</th>
<th>Properties</th>
<th>Supplier/Trade Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wellbond M1440</td>
<td>Polyester</td>
<td>Staple</td>
<td>Coarse plastic like handle Crimp is visible Off white colour</td>
<td>Made from PET Bottles Low melt temperature (4.8 dtex 55m length)</td>
<td>Wellman International</td>
</tr>
</tbody>
</table>

#### 4.5.2 Sampling Method

**4.5.2.1 Fibre Preparation and Web Formation**

The methods of fibre preparation and web formation established in the web formation investigation (outlined in section 4.4) were employed to make webs that incorporated a portion of binder fibre.

The binder fibre was blended with main fibre for each web using the fibre preparation methods. Webs were made using between 10g and 15g of fibre. A ratio of approximately half binder fibre to main fibre was used. Webs consisting of between one quarter of a layer and 4 layers of original web were built up.

In instances where longer fibres were used, the web forming process was adapted to try to retain the original visual qualities of the main fibres. Webs of one hundred percent binder fibre were constructed and the longer main fibres were placed on top of the web whilst it was still on the drum card (H33–H39). The card was then turned to amalgamate the fibres as far as possible. Separate webs, were also made of the binder fibre and main fibre, which were then layered together (H40–H43). Details of each web are given in Table 3 in Appendix 1.

**4.5.2.2 Web Bonding**

The method of bonding the webs drew on the processes used to create fibre webs from Angelina® fibres as discussed in the section 2.3.

Each web was placed between two sheets of release paper and then placed on the lower bed of the heat press. The bed of the press was pushed under the hot plate and the plate lowered for a set time. The plate automatically lifted once the set time had elapsed. The bed was then pulled out from beneath the plate and, after allowing cooling for a few seconds, the release paper was carefully removed from the bonded web.
The press was set to various temperatures ranging from 50°C to 180°C in order to observe the impact of temperature on the webs in question. The time period (or 'dwell time') was set to 10 seconds and each web pressed either once, twice or three times to observe the impact of dwell time. The time remained constant and the number of times that the web was pressed altered to enable the webs to be turned and observed throughout the process.

The details of each sample are given Table 3 in Appendix 1.

4.5.3 Analysis: Observations and Reflections
4.5.3.1 Fibre Preparation and Web Formation
The hand-based methods used to make webs that incorporated binder fibre webs for thermal bonding were successful in that fabrics made from a range of fibres with structural integrity were created. The investigation confirmed, however, that the more thorough the blending at the fibre preparation stage, the more consistent and uniform the structure and qualities of the resulting fabrics were. In relation to this, as previously noted, the fibres that were most effectively opened and carded proved to be the most effectively blended with the binder fibre. As in the previous investigations, where adaptations were made to these methods the qualities of the resulting fabrics were impacted upon.

Adapting the Process for Longer Fibres
As described above, the blending and web formation process was adapted for longer fibres that were difficult to card. The result was essentially a 100% binder fibre web with other longer fibres sitting on top. When bonding these webs only a fine surface layer of longer fibres closest to the binder fibre were bonded (H33–H39). The majority of the longer fibres remained on the surface of the fabric and could be easily pulled off. Although structurally unstable in parts, these samples were interesting because they had contrasting tactile qualities. The binder fibre element resulted in a hard plastic like surface, which contrasted with the softer and more voluminous fibres on the top (H36). This effect was explored further by manipulating the order in which the binder fibre webs and long fibres were layered. For example, placing the main fibre between two layers of binder fibre resulted in a fabric with hard outer surfaces and a soft centre (H41). The reverse was also achieved (H42). The former, however, was easy to pull apart.

4.5.3.2 Web Bonding
Temperature
As anticipated, the temperature at which the fibre layers were bonded affected the strength and handle of the resulting samples. At 50°C the webs were condensed through the pressing
process but were not bonded effectively. They were held together only by the structure of the web itself and, therefore, had little stability. When the temperature was raised to 80°C the plastic qualities of the binder fibre was slightly detected in the handle of the fabric but only a slight bond appeared to have taken place. The level of bonding was assessed by gently tensioning the fabrics and observing their structural integrity from a subjective perspective. At 180°C the fabrics were evidently bonded and were stronger than the other samples. They were perceived by the researcher as having a slightly stiff, crisp, smooth and flat quality to them (H29–H33).

**The Location of the Heat Source**

The side on which the webs were pressed had a subtle effect on the tactile and surface qualities of the resulting fabrics. The side that was nearest to the hotplate of the press appeared more thoroughly bonded than the side that was face down. As a result, the side closest to the press was more compressed, flatter, smoother and harder than the other side. This created a very subtle contrast between the tactile and surface qualities of each side. This contrast was emphasised when the difference between the visual and tactile qualities of the original main fibre and binder fibre was considerable (H59). When the samples were reversed and re-pressed, a more uniform surface quality was achieved (H57).

**Dwell Time**

The length of time (or-dwell time) the webs were subjected to heat and pressure also impacted upon the visual and tactile qualities of the resulting fabrics. The longer the dwell time the greater the extent of the bonding. As was the case when the temperature was increased, when the dwell time was increased, the strength, stiffness and smoothness of the fabric were increased (H31–H36).

**Quantity of Binder Fibre**

The quantity of binder fibre in the web determined to what extent the resulting fabric retained the aesthetic qualities of the original main fibre.

In terms of tactile qualities, the greater the quantity of binder fibre in the web, the stronger, stiffer, smoother and more 'plastic like' the resulting fabrics (H48 and H53). The visual impact of the bi-component in the web was less obvious but still evident. For example, as one may have expected, when the binder fibre was combined with longer fibres, such as ramie, the spaces between the longer ramie fibres tended to be filled. This created a visually denser or less open structure than that which had been created using ramie by itself (H36).
Layering

The quantity of binder fibre in the web also impacted upon how well fabrics that had been built up of a number of layers were bonded together. The greater the amount of binder fibre in the web the more effectively multiple layers were consolidated (this is illustrated well in comparing the viscose and polyester lux samples). This was likely due to the greater number of bonding points on the surface of each layer produced by the greater quantity of binder fibre. The layers were essentially laminated together.

4.5.3.3 Summary

The investigation established a suitable means of producing stable thermally bonded nonwovens using hand-based processes in conjunction with a range of natural and synthetic fibres. The investigation confirmed that binder fibre plays an aesthetic as well as functional role in the production of thermally bonded nonwovens and that variations to the temperature, dwell time and fibre blend impacted upon the qualities of the resulting fabric. It was also confirmed that the way in which the web was formed impacted upon the characteristics of the fabrics produced.

The researcher was able to gain a hands-on understanding of each of the processes and materials that were investigated.

4.6 Design Development

Following the process investigations, a period of work took place in which the possibilities to manipulate the methods established for aesthetic purposes began to be explored. The work focused on the use of the thermal bonding method established because this was the most consistent method investigated.

4.6.1 Materials

The fibres and binder fibre used in this stage of the research were the same as those used in the process investigation described previously. A number of the fibres were coloured using appropriate dyestuffs and procedures before being carded. The dyestuffs and procedures used are documented in Appendix 2. Additional yarns and fibres were also used at this stage of the research.
4.6.2 Approach and Sampling Methods

4.6.2.1 Visual Inspiration
As discussed in Chapter 3, periods of design development were based around the researcher's own methods of design practice. Visual imagery was sourced and manipulated as a source of inspiration and direction for the design work. In this instance, imagery related primarily to the visual and tactile characteristic of the fabrics resulting from the previous investigations. It revolved around photographic imagery of hedgerows and wild flowers reflecting the organic and spontaneous nature of the fabric structures. These images were then physically and digitally layered reflecting the fabric construction process itself and creating abstract visual structures and tonal arrangements. The use of colour at this stage was limited to a tonal range of blacks, whites and greys to enable fabric structure and surface qualities to be focused upon.

4.6.2.2 Drawing on Craft Processes
Techniques used to create decorative motifs and to manipulate colour and texture within traditional felting process were drawn upon. A number of these techniques are documented in craft based books and texts (Burkett, 1979, 1995, Magavok and Lewis, 2000 and Smith and Walker, 2005). Some of the techniques discussed in such texts were explored and adapted for use within the hand-based thermal bonding process that had been established.

4.6.2.3 Sampling Methods
The methods described here were explored. Again, samples that relate to the discussion are noted in brackets where relevant.

The fibre preparation, web formation and thermal bonding techniques that had been explored formed the basis of the sampling process. A ratio of 30% binder fibre and 70% main fibre was used in the fibre blends. The optimum weight range of 10g – 15g was used to create carded webs. The webs were layered (or split) by hand and bonded in the heat transfer press.

The details of each fabric produced are given in Table 4 in Appendix 1.

Creating Contrasting Tone and Texture
Three ways of making fabrics with contrasting texture and tone were explored: firstly, by selecting and blending together fibres that contrasted in terms of either texture or tone at the fibre preparation stage (H65, H72); secondly, by adding the fibres with a contrasting quality to the surface of the web during drum carding at the web formation stage; thirdly, by creating
individual webs of contrasting fibres and layering them together after carding and before bonding (H63, H64).

Creating Fabrics with Contrasting Surfaces on Each Side
At the web formation stage, fabrics with contrasting sides were made by creating individual webs of fibre and layering contrasting webs after carding. The contrasting webs were joined together by thermal bonding.

Incorporating Yarns, Threads and Novel Fibres between Layers of Web
Incorporating yarns and threads was achieved using two different methods. Firstly, at the web formation stage, the yarn was fed into the drum carder with the fibre. As the drum was rotated, the yarn was taken up, wrapping itself around the drum and between the fibres (H75, H76). Secondly, yarns were placed between layers of web after they had been removed from the card and before thermal bonding.

Novel fibres were added to the fabrics in two different methods at the web formation stage. Firstly, novel fibres were placed between layers of fibre whilst it was being drum carded and secondly, novel fibres were placed between layers of web after they had been removed from the card and before thermal bonding.

Embedding Additional Fibres into the Surface of the Web
To embed additional fibres into the surface of the fabrics they were placed on top of carded webs before thermal bonding. However, it became apparent that only the additional fibres that were in direct contact with the surface of the web were effectively bonded. To overcome this webs were bonded once, at a low temperature, in the heat transfer press as a method of 'pre-bonding'. This method relates to the idea of pre-felts discussed in Smith and Walker (2005 p. 26) and gave the webs enough structural integrity to withstand the process of lightly tacking additional fibres to their surface using a conventional barbed needle. The fibres were pushed through the surface of the web and entangled as the needle was drawn back through the web. The webs were then re-bonded to fix the additional fibres in place (H68, H69, H70, H71).

Controlling the Placement of Coloured Fibres
Controlling the placement of colour fibres in the web was achieved in the same way as it is in traditional drum carding processes. As described in most texts on hand felting, and confirmed in regard to industrial carding processes by both Marsden (1977) and Bartlett's (1997)
research, arranging contrasting fibres vertically adjacent to one another as they are fed into the card results in a web in which the fibres are arranged in the same manner. When using certain layering systems, arranging the fibres in a horizontally adjacent manner as they are fed into the card results in a web in which the first colour sits on the bottom and the second one above it. Placing coloured fibres on top of one another as they are fed into the card results in a web in which the contrasting fibres are blended together. These methods were appropriated using the drum carder.

4.6.3 Analysis: Observations and Reflections

4.6.3.1 Contrasting Texture and Tone

Achieving this was relatively straightforward and relied upon the sensitive preparation of the chosen fibres. As referred to previously, the extent to which the fibres were opened affected their visual and textural impact in the resulting fabric. For example, the wool mix fibre had a nep in it that created a strong texture in the resulting fabric. As shown in Figures 75 and 76 the more the fibres were opened and blended the less prominent the nep in the resulting fabric (H65, H66, H72). The ratio of each fibre with the blend also affected the level of contrast achieved. Using the second method enabled contrasting fibres to be positioned in the web more deliberately, this allowed more control in terms of composition.

Contrasting Surfaces

Again, this was relatively easy to achieve and the types of fibre selected were the most important consideration for achieving suitable contrast with regard to texture and tone. The density of the individual layers also impacted upon the level of contrast achieved. For example, the thinner the layers, the greater the extent to which one side of the fabric could be seen through the other (H63, H78). The denser the layers, the more distinct the qualities of each side (H76). This is shown in Figures 77-79.
4.6.3.2 Incorporating Yarns, Threads and Novel Fibres between Layers of Web

Both methods used to incorporate additional materials between layers of web worked well. However, adapting the process in this way did affect the quality of the bond achieved. The additional materials appeared to prevent the fibre directly above and below them from being bonded. This created a 'pocketing' effect within the structure of the fabric (H70, H71). The extent to which this occurred seemed to depend on the thickness and quantity of incorporated materials. The thicker and denser the material the greater the 'pocketing'. The finer the material the less impact on the consistency of the bond across the fabric.

These methods created an interesting visual effect as shown in Figures 80-82, particularly when the fabric was viewed in front of a light source. It was felt that developing more control over the placement of the fibres within the layers could potentially create visual depth and structure. Visual and textural contrast was created where an area of the top layer of web was uneven and the trapped fibres broke through. Controlling this in terms of placement showed potential for compositional work.
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Although both methods used were effective, it was difficult to achieve a high level of tension when incorporating yarn. When the webs were removed from the drum, the yarns were relaxed before being fixed into place, which changed their appearance. However, the samples made in this way were visually interesting as the linear qualities of the yarn contrasted the textural surface of the fibre webs. When arranged as a regular stripe the yarns also gave the fabrics a greater sense of structure and composition, as illustrated in Figures 83-85. There is further potential within this technique for creating, visual and tactile contrast, visual depth and pattern.

4.6.3.3 Embedding Additional Fibres into the Surface of the Web

The methods used to achieve this effect were successful to a certain extent. The fibres were not firmly embedded into the surface but more loosely attached. The method did, however, create an interesting effect on the reverse side of the fabrics where small loops of fibre come through onto the surface in the areas that had been tacked (H68, H69, H70, H71). The effects achieved relate to the idea of designing using the notion of fibre transfer within needle punching as explored by Marsden (1977) and some of the appliqué like techniques previously explored by designers such as Tait and Style. If further developed, the method could potentially be used to create numerous fibre based decorative effects on the surface of the fabric. Examples of the fabrics made are shown in Figures 86 and 87.
4.6.3.4 Controlling the Placement of Coloured Fibres
These methods were successfully implemented to achieve graduated tone. The methods used also showed potential for developing fabrics with graduated texture enabling a change in surface qualities across a web to be achieved.

4.6.3.6 Summary
The design development aspect of this stage of the work was successful because a range of methods with which to manipulate hand based nonwovens has established for design purposes. The fabric samples produced illustrate these methods successfully and show potential for further development. The overall quality of the fabrics, however, could be improved by further refining the techniques used.

4.7 Chapter Summary
Two methods of chemical bonding have been described and one method of thermal bonding. Further to this, a period of design development work utilising the successful aspects of the methods explored has been outlined. Stable nonwovens were achieved and a number of observations were made in relation to the impact that various aspects of these processes had on the quality of the resulting fabrics. Further to this, a number of methods to manipulate these processes for design purposes were outlined.

In summary, within a studio context, the use of a bi-component binder fibre in conjunction with heat and pressure proved the most efficient and consistent method of bonding carded webs. Whilst a number of fabrics were produced using print and spray bonding techniques the results were inconsistent. It would have been beneficial to needle-punch the fabrics before printing or spraying, which may have enabled a greater range of surface qualities to be explored by printing or spraying a range of chemical substances. This is a potential area for further work.

Whilst a number of the observations made during the investigations are already known, the work conducted did enable the researcher to gain hands on understanding of nonwoven processes at their most basic level. It also provided a basis for exploring the relationship between craft and industry within the area of nonwoven production.
5.1 Introduction

The last Chapter described a series of investigations that established the use of hand-based textile processes to make chemically and thermally bonded nonwovens. A number of ways in which to manipulate these processes for design purposes were explored. It was confirmed that the surface qualities of the fabrics made depended primarily upon the type of fibre used and that these surface qualities could be subtly manipulated through the fibre preparation, web formation and bonding processes, and, through the incorporation of additional materials to the fibre webs.

The methods established were based on low technology equivalents of industrial nonwoven technologies and the design development drew on traditional craft based felting techniques. To explore the translation of the ideas developed using industrial nonwoven technologies, a series of investigations using pilot scale industrial carding and bonding equipment were conducted, which at points also incorporated needle-punching.

5.1.1 Aims and Approach

It was observed in Chapter 4 that, the most consistent means of making nonwovens by hand was by creating carded webs from a blend of main fibre and binder fibre and by bonding these webs using heat and pressure. This method, therefore, formed the focus of the investigations conducted during this stage of the practical research.

The aim of each investigation was to explore the opportunities for manipulating carding processes and thermal bonding processes which utilize heat and pressure for design purposes at a pilot scale production level. The investigations were driven by the period of design development described in Chapter 4. This stage of the practical work also set out to establish a mode of practice and working environment that could be sustained throughout the research to enable extensive design development.

5.1.1.1 Collaboration

In order to conduct the work, a collaboration was formed with nonwoven manufacturers Texon UK ("Texon") to conduct an initial period of work. However, due to unforeseen circumstances this collaboration was unsustainable and therefore contact was made with The Nonwovens Research Group at Leeds University ("NRG") and The Centre for Materials Research and Innovation at Bolton University ("CMRI"). Both are academic centres of excellence of nonwovens research and have pilot scale facilities. A period of work was conducted with each.
Chapter 5 Practical Research Stage 2

This Chapter covers the following areas in connection with each period of work:

- materials used;
- sampling methods and equipment; and
- observations and reflective analysis of the processes and resulting fabrics.

The analysis focuses, in particular, on the observations made in regard to process manipulation and on the similarities and differences observed between the fabrics produced using the pilot scale equipment and those produced using the hand-based methods.

Each fabric produced is numbered and documented in Appendix 3. When specific samples are referred to in the text their number is given in brackets.

5.2 Pilot Scale Work with Texon

Texon is part of the Texon International Group which manufactures a range of nonwoven and cellulose products using a range of technologies. At the time of research, Texon conducted its research and development using small-scale industrial equipment at their Leicester based pilot plant.

A proposal to work with Texon was put forward. A period of work was agreed in which sampling could be conducted at the pilot plant with the assistance of Texon's technical staff. A selection of fabric samples from the design development aspect of Stage 1 of the practical research was shown to the technical staff and possible methods of reproducing the ideas using the pilot scale equipment were discussed. A series of samples were then made, which explored different web making and bonding parameters in relation to the design ideas established in Chapter 4. The materials, equipment and sampling methods that were used are described below.

5.2.1 Materials

The pilot scale carding system used at Texon was originally designed to process wool fibres. It was, however, routinely used to process a range of synthetic fibres including polyester, viscose rayon,nylons and acrylics that ranged from 1.5 to 7 dtex with fibre length of around 37.5mm. It was suggested that fibres of up to 150mm long could be processed but that fibres any longer than this would wrap around the rollers and cause production problems. Fibres with some degree of crimp were seen as the most suitable for use because those without any crimp tended to fall out of the bottom of the card during processing. It was agreed that an 'experimental' approach to the work be adopted. Working with care, the fibres used in Stage
1 of the research were used, as shown in Table 1, in combination with a low melt polyester binder fibre.

A fibre called T254 manufactured by Hoechst was used as the binder fibre. This fibre was routinely used in the pilot plant and its bonding characteristics familiar to the technical staff. Details of this fibre are given in Table 3.

<table>
<thead>
<tr>
<th>Fibre Name</th>
<th>Fibre Type</th>
<th>Fibre Form</th>
<th>Aesthetic Qualities</th>
<th>Generic Qualities</th>
<th>Supplier/Trade Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoechst T245</td>
<td>Mono-component polyester</td>
<td>Staple Fibres</td>
<td>Bright white Visible crimp Soft Handle</td>
<td>Low melting point</td>
<td>Hoechst</td>
</tr>
</tbody>
</table>

Table 3: Details of Hoechst T245, the binder fibre used during the work conducted with Texon.

5.2.2 Sampling Method

5.2.2.1 Fibre Preparation and Web Formation

Fibre preparation and web formation were conducted using a small-scale industrial carding unit as illustrated in Figures 88 and 89. This type of machine is primarily used by Texon to assess and establish carding parameters for full-scale nonwovens production.

The machine is comprised of a series of rollers covered in metal teeth or wires. The process for fibre preparation and web formation is as follows: (1) the fibre to be processed is weighed (a maximum of 300g) and spread evenly over the feeder sheet; (2) the machine is started and the feeder sheet carries the fibre forward until it is gripped by the 'feed rollers' and taken into the card; (3) The fibres are preliminarily opened by the feed rollers and then are further opened by the 'tummer roller' before they are fed into the swift; (4) the 'worker' and 'stripper rollers' perform the carding action against the 'swift roller' and the fibres are progressively opened, disentangled and distributed until an even layer of fibre forms on the surface of the swift roller; (5) the 'fancy roller' lifts the fibres from the wire teeth on the swift enabling them to be effectively removed by the 'doffer'; (6) the carded fibre is taken from the doffer by the 'flycomb' and is introduced by hand to a felt pad on the lap drum; (7) as processing continues the fibre is taken up by the lap drum and condensed by the pressure roller; (8) when all the fibre has been processed, the resulting fibre web is cut by hand and removed from the lap drum, and; (10) the process is repeated with the web fed into the card at right angles to the original path in order to produce a more even distribution of fibres.
Webs were made using fibres of different types, blends and of different weights, following the procedure outlined in section 5.2.2.1. To blend the main and binder fibres the required quantity of main fibre was distributed as evenly as possible over the surface of the feed sheet with the required quantity of binder fibre then distributed as evenly as possible on top.
The procedure was manipulated at the fibre feeding stage (i.e. when the fibre was placed on the feed sheet and fed into the card) and web take-up stage (i.e. when the layers of fibre were taken up by the lap drum to create the web) of the process to achieve the ideas embodied within the fabric samples produced during Stage 1. The methods used are outlined below and the making details of each web produced are documented in Table 5 in Appendix 3.

**Contrasting Tone and Texture**

As in Stage 1, creating texture and tone within the fabric samples was achieved by the careful selection of fibres in terms of texture and tone and by manipulating the fibre blend. In Stage 1 contrasting fibres were also added to the surface of the drum card during carding but this was not possible in this case because the pilot card was fully enclosed. Instead, contrasting fibres were gently placed on top of the fibres as they were transferred from the doffer to the lap drum.

Making fabrics with contrasting sides was achieved in the same way as in Stage 1 - by layering individual webs made from contrasting fibres. It was also achieved by feeding one lot of fibre behind the other on the feed belt. The first fibre was carded and layered on the lap drum and the second fibre layered directly on top of it.

**Incorporating Yarns, Thread and Novel Fibres and Fabric Motif’s Between Layers**

As in Stage 1, threads, novel fibres and fabric motif’s were incorporated between layers in two ways. Firstly, by placing additional materials between layers of fibre during the carding process. This was achieved by gently placing the additional materials on top of the fibres as they were transferred from the doffer to the lap drum or by placing them on the surface of the web as the lap drum rotated. Secondly, additional materials were placed between fibre webs after carding.

Yarns were also incorporated into the fabrics during the web formation process by inserting an end of yarn into the initial layer of fibre taken up on the lap drum. As the lap drum rotated, the yarn was taken up from a cone, placed on the floor, at the same rate as the web. This meant that there was one end of yarn between each layer. The yarn remained in the same position between each layer unless guided by hand across the web. At this stage only fine yarns were incorporated into the webs.

**Controlling the Position of Fibres in the Web**

As confirmed in Stage 1, controlling the placement of coloured fibres in the web (from a macro perspective) to realize different compositional effects was achieved by controlling the
order in which the fibres were fed into the card. This was achieved by ordering the fibres in a horizontally adjacent manner on the feed sheet. Fibres with different tonal qualities were used to achieve graduated tone in the resulting fabrics and the same method was used to create graduated textural change across the surface of the fabrics by using fibres with different textures and handles.

**Manipulating the Weight of the Fabrics**

The weight of the fabrics was controlled predominantly by controlling the amount of fibre fed into the card for each web.

**Manipulating the Handle and Surface Qualities of Fabrics**

Within this aspect of the sampling method, the handle of the fabrics was manipulated by the ratio of binder fibre to main fibre. This was not, however, the focus of the work at this stage.

5.2.2.2 Web Bonding

Work was focused on the use of a heated calendaring system to thermally bond the carded webs. The calendering system was used to apply heat and pressure to the fibre webs. It was felt that, to some extent, this reflected the heat pressing process used in Stage 1. For reasons discussed below, needle punching was introduced as a means of tacking and compressing webs before calendaring. The sampling method and equipment used are described below.

**Calendering**

The calendering system used is illustrated in Figures 90 and 91. The diagram shown is from the service manual for the machine. This system was primarily used by Texon for condensing sample fabrics to a specified thickness but it was also used on occasion to heat bond and laminate fabrics. The system works by applying heat and pressure to fabrics as they are fed between the two heated cylinders at a given speed. The pressure applied to the fabric, the speed at which the rollers turn and the gap between the two rollers can be adjusted to manipulate the degree of consolidation achieved and the rate of production. The rollers are heated using hot oil, the temperature of which can be controlled using a temperature control unit. During the work conducted for this research, the calender was used as follows: when all of the parameters were set and the rollers were in their down position, the drive was activated and the fabric was fed by hand under the front guard and between the two rollers; the movement of the rollers drew the fabric through; as the fabric passed between the rollers, it
was subjected to the set heat and pressure; the fabric was then collected from the rear of the machine.

At Texon, the calender was typically run at a mid pressure (the maximum being 6 tons), and at a speed of two metres per minute. The temperature was typically adjusted within the range of 50°C to 225°C and the gap between the rollers adjusted between 0mm to 0.6mm.

For this investigation the calender was set to mid-pressure; the speed to two metres per minute and the temperature was set within the bonding range of the binder fibre (i.e. within the range 120°C–150°C).

Controlling Fabric Thickness
The gap setting between the rollers was adjusted for each web as a means of controlling the extent to which the webs were condensed and the subsequent thickness and volume of the web.

The calendering details for each web produced are documented in Table 6 in Appendix 3.
Heat Pressing
A number of the webs were bonded using the heat transfer press used in Phase 1 of the work in order to enable comparisons to be drawn with calendaring. The making details for each fabric produced are given in Table 7 in Appendix 3.

Needle-Punching
Needle-punching bonds webs by mechanically entangling the individual fibres (as outlined in Chapter 2). The needle-loom used at Texon is illustrated in Figure 94. It was used during this work as follows: (1) each web was placed on the feed sheet and was fed into the machine at a given speed as it was activated; (2) the web passed through the machine at a given rate of advance, and was repeatedly punched by needles, at a given number of strokes per minute and to a given depth; (3) the web emerged from the needle boards and was delivered to a set of compressing rollers and; (4) having passed through these, the web was collected, by hand, as it came out from between the rollers.
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The rate at which web advances through the machine, the number of punches delivered to the web per minute and the number of needles per unit width of the needle board determines the punch density of the fabric. Punch density describes the number of needle penetrations per unit area of the fabric (punches/cm²). The punch density directly affects the resulting fabric’s properties and dimensions, and can be manipulated as such. The depth to which the needles penetrate the web also impacts on the fabric’s properties. A mathematical equation is used to calculate Punch Density (Swarbrick, 2007).

Needle punching was not the focus of these investigations and so the parameters and thus the punch density were kept constant. Within this stage of the research, the loom was set to 150 strokes per minute at 8mm needle penetration depth using 3.5” conventional barbed needles. The making details for sample are documented in Table 1 in Appendix 5.

At this stage, needle punch was used to enable the researcher to gain hands on understanding of this technology. In Stage 3 of the practical research, the parameters noted above were adjusted and the effects on the resulting fabrics observed.

Multiple Bonding Methods

A number of the webs were bonded using a combination of the methods outlined. The processing details are documented in Tables 5, 6 and 7 in Appendix 3.
5.3 Work with the Nonwovens Research Group at Leeds University

The Nonwovens Research Group at Leeds University (‘NRGroup’) undertake a wide range of research projects based around the development of nonwovens for a range of industrial sectors and applications including; agricultural, automotive, construction, medical, filtration and clothing. The NRGroup’s facilities include a number of carding lines, needle looms, hydro-entanglement and chemical and thermal bonding facilities (www.nonwovens.leeds.ac.uk, 2006).

5.3.1 Aims and Approach

The Texon facility could no longer be used, due re-organisation within the company. The NRGroup was therefore approached and some time in their laboratory was arranged. As with the work conducted at Texon, the work with the NRG drew on Stage 1 of the research. The techniques used to manipulate the carding and bonding processes for design purposes that were explored at Texon were adapted for the equipment in the NRGroup laboratory. A series of samples were made that explored a number of different web forming and bonding parameters within the confines of the equipment. The work focused in particular on observing the effects of different calender settings. The materials, sampling methods and equipment that were used are outlined in sections 5.3.2 and 5.3.3 respectively.

5.3.2 Materials

The fibres used were the same as those used in Stage 1 of the work (Table 1). Wellbond M1440 was used as the binder fibre (Table 2).

5.3.3 Sampling Method

5.3.3.1 Fibre Preparation and Web Formation

Fibre blending and web forming was achieved using a card and cross-lapping system. The card functioned in essentially the same way as it was used at Texon but differed in terms of scale and the mechanism used to layer the web. The carding width was one metre and the web was layered using a vertical cross-lapping system similar to that shown in Figure 93.

Fibre was fed into the card by means of a feed belt and emerged from the carding rollers onto a conveyor belt. The web travelled upward along the conveyor belt to a pivot point from which two reciprocating belts layered the web onto an output conveyor belt. The output belt then carried the web towards a needle-loom (for punching or removal from the belt) at a given rate. The rate at which the belt moved affected the rate of layering and subsequently the thickness and weight of the web.
Webs were made from a variety of fibre types, fibre blends and fibre quantities. Each fibre blend was carded to open and blend the fibres and then carded a second time to produce the final web. The output melt was turned off during production. This meant that the layers of fibre were laid on top of each other to create 1m² fabrics. As such, fibre was not wasted making long lengths and it was more straightforward to calculate the approximate amount of fibre needed for a web of certain weight. This procedure was adapted in a number of ways for design purposes which are described below.

**Contrasting Tone and Texture**

As with the work carried out at Texon, the texture and tone created within the fabric samples was achieved by the careful selection of fibres in terms of texture and tone and by manipulating the fibre blend. During Stage 1, contrasting fibres were also added to the surface of the drum card during carding to manipulate texture and tone. At Texon, texture and tone were further manipulated by placing contrasting fibres gently on top of the main fibre blend as it was transferred from the doffer and the lap drum. The NRGroup equipment was much larger than that at Texon. The card and lapping system were surrounded with guards for health and safety purposes which meant that it was not possible to get close to the fibre layers during production to place fibres onto their surface. The additional fibres, therefore, had to be thrown from the edge of the unit onto the fibre layer.
Making fabrics with contrasting sides was achieved by layering individual webs made from contrasting fibres.

**Incorporating Yarns, Thread and Novel Fibres and Fabric Motifs between Layers**

As in Stage 1, threads, novel fibres and fabric motifs were incorporated between layers of fibre by placing additional materials between the layers of fibre during the carding process. This was achieved, using the Texon equipment by gently placing the additional materials on top of the fibres as they were transferred from the doffer to the lap drum or by placing them on the surface of the web as the lap drum rotated. It was not possible when using the NRGroup equipment to place additional materials directly onto the web's surface owing to the scale of the machinery. Therefore, additional threads, fibres and fabric motifs had to be thrown or scattered on the fibre layers from a distance.

It was also not possible to incorporate continual ends of yarn into the webs (as it was using the Texon card) owing to the different layering mechanism. At this stage of the research, a way in which to feed yarn between the layers of web was not resolved.

**Controlling the Position of Fibres in the Web**

As confirmed in Stage 1, controlling the placement of coloured fibres in the web by controlling the order in which the fibres were fed into the card (from a macro perspective) allowed different compositional effects to be achieved. As in Stage 1 and at Texon, this was achieved using the NRGroup equipment by ordering the fibres in a horizontally adjacent manner on the feed sheet. It needs to be noted, however, that this only worked using the NRGroup system owing to the fact that the output belt on the layering system remained still during production. Had it been moving, the different coloured or textured fibres would have been positioned differently in the final web.

**Manipulating the Weight of the Fabrics**

The weight of the fabrics was controlled predominantly by controlling the amount of fibre fed into the card for each web. Again, it was possible to roughly approximate the weight of the webs when working with the NRGroup equipment because the output belt remained still during production.
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**Manipulating the Handle and Surface Qualities of Fabrics**

Within this aspect of the sampling method, the handle of the fabrics was manipulated by the ratio of binder fibre to main fibre. However, at this stage of the research this was not a key focus of the work.

The making details of each web produced are documented in Table 8 in Appendix I.

5.3.3.2 Web Bonding

During the work conducted with the NRGroup, web bonding focused on the use of hot calendaring. Needle punching was also introduced as a means of tacking and compressing webs before calendaring. The work built on the work conducted at Texon by looking in greater detail at specific calendaring and needle-punching parameters.

**Calendering**

The calendaring system used was originally designed for use in the paper making industries and comprised of two smooth rollers that were 22cm wide which could each be heated to specific temperatures. The system was, therefore, similar to that used at Texon in that the heat, pressure and speed of the rollers could be adjusted. The gap between the two rollers was, however, set to nip point and could not be adjusted.

Each web produced was calendered at different temperatures, pressures and speeds and the effects on the qualities of the resulting fabrics were observed. This enabled further understanding of the impact of different process parameters on the qualities of the resulting fabrics to be gained. Details of the parameters used for each sample are given in Table 9 in Appendix 3.

**Needle Punching**

Needle punching was incorporated into the sampling procedure to tack the webs to give them more structural integrity for handling and transportation and to compress and consolidate webs prior to thermal bonding.

The needle loom used was integral to the cross-lapping line, and webs were fed directly into it at a given rate. As discussed earlier in this chapter (section 5.2.2.2), there are a number of parameters that can be adjusted in needle punching to control the properties of the resulting fabric. At this stage of the work, the effect of different needling depths on the resulting samples and their suitability for calendering was observed. The samples produced are documented in Table 9 in Appendix 3.
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*Heat Pressing*

A number of the webs were bonded using the heat-transfer process as described in Stage 1. Details of pressing are given in Table 10 in Appendix 3.

5.4 Work with the Centre for Materials Research and Innovation at Bolton University

The work carried out at Texon and with the NRGroup explored the translation of nonwoven design ideas developed using hand-based methods onto pilot scale industrial equipment. The work focused on the adaptation of sampling procedures for design purposes and on the effects of different processing parameters on the resulting fabrics, including in particular, the use of carding and calendering in conjunction with a binder fibre. The work with the NRGroup focused on the effects of different calendering parameters. As outlined in the observations and analysis in section 5.5, following the work with the NRGroup it was felt that further exploration into the quantity of binder fibre in the webs would be beneficial. Owing to the limited time available to use the NRGroup’s machinery, part of the work was carried out at the Centre for Materials Research and Innovation at Bolton University (‘CMRI’).

5.4.1 Aims and Approach

It was felt that an increased focus on webs with different proportions of binder fibre in them to observe the effects of calendaring would be beneficial at this stage in the research. A smaller number of fibres were selected and a series of webs of each fibre were made at CMRI. Samples of each web were then calendered using the equipment at the NRGroup.

5.4.2 Materials

Five fibres were selected for use alongside Wellman M1440 as the binder fibre. These fibres had quite different and distinct visual and tactile characteristics and were selected from the initial group of fibres listed in Table 1. The fibres selected were silk, wool/linen/silk mix, viscose, ramie and tri-lobal nylon. Further to this a high lustre nylon yarn, lace fabric pieces and calico fabric pieces were used within the samples.

5.4.3 Sampling Method

5.4.3.1 Fibre Preparation and Web Formation

Fibre preparation and web formation were carried out using a carding and cross-lapping system at CMRI as shown in Figures 94 and 95. The carding and cross-lapping system differed to the system at the NRGroup in that it was a horizontal (rather than a vertical lapping
system). The card was also of a narrower width. The diagram shown in Figure 96, shows how the lapping system worked.

**Figure 94:** Card, Cross-lapping, Needle punch and Thermal Bonding (CMRI).

**Figure 95:** Carding Unit (CMRI)
Four samples of each fibre were made, each with a different ratio of binder fibre to main fibre. Based on the qualities of the previous samples, each fibre type was used to create a different weight of web. For example, the ramie was used to create lightweight webs, the viscose to produce medium weight webs and the silk to produce heavy.

For each sample, the fibres were weighed and carded once to open and blend the fibres. The fibres were then carded and cross-lapped to form webs. The output belt travelled at a constant speed to make larger webs for subsequent processing. The speed was controlled by the technician using the attached control unit to achieve the desired weight of web. Each group of webs incorporated one of the design techniques being developed.

**Incorporating Yarns, Thread and Novel Fibres and Fabric Motif's between Layers**

Fabric pieces were incorporated between layers of web by placing them on the surface of the fibres as they travelled between the card and the cross-lapper. Lengths of yarn were cut to a predetermined length and placed on to the fibre layers in the same way.

**Contrasting Tone and Texture**

Making fabrics with contrasting sides was achieved by layering individual webs made from contrasting fibres. The first web was made and removed from the lapping system. As the second web was being made the first web was fed underneath the second, as it was cross-lapped.

The ratio of fibre used in each web and the making details are documented in Table 11 in Appendix 3.
5.4.3.2 Web Bonding
The webs were needled to give them some stability for transportation to the NRGroup and to condense them before calendering. At this stage in the work, the needle punching parameters were controlled by the technician and remained constant (these parameters are observed in more detail in Stage 3). Following punching, samples of each fabric were calendared using the system at the NRGroup. Again different temperatures, pressures and speeds were applied and the effects on the resulting samples observed. The bonding details for each sample are given in Table 12 in Appendix 3.

5.5 Analysis: Observations and Reflections
The observations, reflections and analysis documented here looks at how the pilot scale machinery that was accessed at Texon, the NRGroup and CMRI could be used for design purposes. The success of adapting sampling methods for specific purposes and the impact of manipulating certain production parameters on the resulting fabrics is discussed. Issues relating to the working environment/context in which the research took place are also considered together with the level of fluidity between the hand-based sampling methods used in Stage 1 and pilot scale methods.

5.5.1 Contrasting Tone and Texture
Fabric tone and texture were initially manipulated at the fibre preparation and web forming stage of the process. This was achieved by selecting textured fibres, manipulating the fibre blend, adding contrasting fibres to the webs during carding and layering individual webs of different fibres.

5.5.1.1 Carding
The automated nature of the equipment used in each phase of work meant that the level of fibre opening achieved was much greater and more consistent than that achieved using the hand-based equipment. A number of the fibres that had created a distinct texture in the fabrics made when using the hand-based equipment were less distinct when using the industrial equipment. For example, the speckled effect created by the nep of the wool/linen/mix fibre, as shown in Figure 97 was less evident in the samples created using the industrial equipment, as shown in Figure 98, where the resulting fabric had a subtle texture and the speckled effect created by the fibre nep was less distinct. The fibre was opened more thoroughly and so the nep became less evident in the resulting fabrics.
The effect that had been created, when using hand-based processes, by using unopened slivers of longer fibres (such as silk and ramie), as shown in Figure 99 was more difficult to achieve using the pilot scale equipment. The larger, more powerful pilot card distributed the longer fibres evenly within the web creating a more uniform and smooth surface without visible 'clumps' or lengths of fibre. Although a distinct quality of web was achieved using longer fibres, their visual and tactile impact was less evident, as shown in Figure 100. The greater the number of times the fibre was carded the more uniform and smooth the surface became.

5.5.1.2 Layer Systems
Contrasting tone and texture was also achieved by layering together individual webs of contrasting fibre types and colour. Using the Texon equipment, the order in which the fibres were fed into the card was controlled and individual webs were layered by hand following carding (T16, N4). As in Stage 1, when denser webs were layered together (H78), fabrics
with distinctly contrasting sides were created. The more translucent the individual webs, the
greater the extent to which one web could be seen through the other, creating a textured
appearance (N1). When using the pilot scale equipment to sandwich layers of one fibre type
between layers of another, an interesting visual and textural effect was created where the
fibre in the middle broke through onto the surface of the fabric (T16 and NRG4). These
effects are illustrated in Figures 101-103

The type of layering system used impacted on the extent to which these techniques could be
used. The lapping system used at Texon was easy to control because the fibre layers were
simply layered on top of each other on the lap drum. However, this meant that the size of
web was limited to 70cm x 90cm. The cross laying system at the NRGroup and CMRI
enabled continual lengths of fabric to be made, but activating the output belt made it more
difficult to determine the position of specific fibre layers. This meant that rather than creating
a web with fibre layers directly on top of one another, webs that moved from one fibre to the
other were created. However, this was overcome by making a completely separate web and
by feeding it under another as it moved along the output belt. This allowed a continual length
of fabric to be made.

5.5.2 Adding Novel Fibres and Fabrics to Create Visual Depth
Using all three pilot lines, additional fibres and fabric motifs were added between fibre layers
during the web formation process. This largely relied on hand intervention and so the size,
speed and scale of the line impacted on the extent of control that was possible.

5.5.2.1 The impact of Speed and Scale
The speed of all three lines meant that the additional materials had to be placed between the
fibre layers very quickly.
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**Texon**

Owing to the size of the equipment used at Texon it was possible to stand next to the lap drum and place the additional materials onto the surface layers of the fibre as they moved around the drum. This allowed a degree of control in terms of where the additional materials were placed and their resulting composition in the final fabric, as shown in Figure 104 (T15). However, because the drum rotated at speed only lightweight materials with some 'grip' remained on the surface layer. Heavier materials and those that were shiny and smooth (i.e. not much grip) tended to fall from the surface of the web as it rotated around the drum.

**NRGroup**

Additional materials were also successfully added between fibre layers using the NRGroup's machinery but there were more limitations regarding which materials could be used and the amount of control that was possible. Owing to the scale of the carding unit, it was not possible to get close enough to the web to 'place' fabric pieces and fibres onto the web whilst it was in operation. Therefore, the pieces had to be thrown or scattered on the moving web as it travelled from the card to the lapping device. This meant that there was little control over placement, which limited the design possibilities in terms of composition but created a distinct random effect, as shown in Figure 105 (N2). Moreover, only fabrics and fibres that were heavy enough to be thrown could be used but fabrics that were too heavy tended to pull and distort the fibre layers as they moved between the reciprocating belts. Owing to the size and speed of the carding system, it was not feasible to stop and start the belts to enable more precise placement. The machine took a few seconds to come to a halt and the fibre layer could have been broken.

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**Figure 104:** Sample T15  
**Figure 105:** Sample N2
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The carding and cross-lapping system at CMRI was the most versatile and effective in terms of placing fibres and fabrics between fibre layers. Direct access to the feed belt was possible owing to the smaller size of the system, enabling fabric pieces and additional fibres to be placed rather than thrown onto the web. The smaller size of the system made it more feasible to stop and start the web in production (however, some breakages within the fibre layers did occur). This meant that the materials could be intentionally placed enabling greater possibilities in terms of composition. Owing to the nature of the process, however, the effects compositions were essentially 'one-off'. The horizontal nature of the lapping system also allowed a broad range of materials of different weights to be effectively included, as they did not tear the fibre layers as they moved from one belt to another. A number of fabrics produced in Stage 4 of the practical research evidence this.

5.5.2.2 Incorporating Yarns

Again, the individual nature of each system impacted upon the ability to incorporate yarns efficiently and effectively between fibre layers.

**Texon**

As outlined in section 5.2, yarns were incorporated successfully using the Texon equipment by inserting an end of yarn into an initial layer of web on the lap drum. As the lap drum rotated, yarn was taken up. This meant that there was one end of yarn between each layer. The yarn remained in the same position between each layer unless guided by hand across the web (T8, T9, T10). As this process allowed yarn to be incorporated directly and continually from the cone and for it to be manipulated by hand it was possible to tension the yarn to some degree, as shown in Figure 106. At this stage, only fine yarns were incorporated into webs because they had been successfully bonded using calendering, heat pressing and needling.

**CMRI**

When using the CMRI system yarns were placed between fibre layers as they travelled from the card to the lapping device (as when incorporating fabric pieces). As the machine could be stopped and started it was possible to intentionally place cut lengths between layers of web, as illustrated in Figure 107. This was, however, a slow process and it was more difficult to control the yarn than it was when using the Texon equipment.
NRGroup
Due to the scale and speed of the NRGroup equipment, at this stage in the research, it did not seem feasible to incorporate yarns,

5.5.2.3 Applying Heat and Pressure to Webs with Additional Materials between Layers
During the calendaring process heat and pressure are applied to the webs to compress and flatten them often resulting in smooth and sometimes shiny surface as well as activating bonding.

When webs with thick slivers of fibre between the layers were calendered, they were compressed and bonded but also puckered and tore in the areas around the fibre sliver, as shown in Figure 108-110 (T4, T5, T6). This did, however, create an interesting three dimensional effect in webs composed of 100% binder fibre, as shown in Figure 110 (T6). Webs that contained flatter fibres, fabrics and yarns were more successfully bonded using the calendaring process.

The heat press was more effective at bonding webs with thick slivers of fibre between layers. This was because the bed of the heat press was soft, allowing some movement and give as pressure was applied to the webs. However, as observed in Stage 1 the use of the heat press did create a pocketing effect around embedded fibres and fabrics. This happened to a lesser extent when webs were calendered, and was reduced further when webs had been lightly needle punched before the application of heat and pressure. The needling process entangled the additional materials with the actual fibre web (rather than bonding around them). It also reduced the volume of the webs making it easier to calender and heat press them.
5.5.3. Controlling the Placement of Fibres in the Web

As confirmed in Stage 1, the different colours and textures could be deliberately positioned to create stripes of colour by controlling the order in which the fibres were fed into the card. This technique was used to create graduated tonal and textural change across the surface of the fabric as illustrated in Figure 111 (N2). When using the pilot scale equipment, more precise results were achieved than when using the hand-based equipment. However, the nature of the different lapping systems employed impacted on how far this technique could be taken.

5.5.3.1 Layering

Each of the layering systems used was different (as discussed under 'sampling methods') and each had a different impact upon the ability to control the placement of fibre in the web (and therefore, the compositional possibilities for design). The system used at Texon allowed a high degree of control enabling almost exact sections of colour to be established within the webs (ref, figures above). The fibres appeared in the web in the same manner as they had been placed on the feed belt. This was also the case when using the vertical and horizontal
cross-lappers at the NRGroup and CMRI respectively, but only when the output belts were kept still. As described above, when the output belt was kept still, it was possible for each layer of web to be placed directly on top of the other allowing precise placement to be achieved. When the output belts were put in motion, the web moved as each layer was laid, distorting the graduated colour and striped effects. However, the extent to which the effects were distorted could potentially be controlled by adjusting the speed of the input and output belts. Brydon (2007, p.67) explains that the angle at which the layers are laid down is determined by the ratio the input speed to output speed and that the linear production speed is a function of both the lay down width and the number of layers. The compositional possibilities for the production of lengths of fabric using this technique are to some extent limited. To produce longer or continual lengths of fabric with graduated colour, an alternative technique could be achieved by carding one colour directly after the other.

5.5.3.2 Coloured Fibres
The ability to use coloured fibres was to some extent restricted by using the pilot scale equipment. This was because each time a coloured fibre was carded, remnants of it remained in the carding system meaning that they could potentially find their way into subsequent webs. These fibres were often visually evident and on certain occasions found their way into subsequent fabrics creating an undesirable effect. To avoid this result the carding system had to be cleaned out using white fibre between colour changes. This process took up limited time and fibre.

A further consideration when using coloured fibres was that the pilot lines were going to be used for research into medical fabrics. The impact of coloured fibres finding their way into trial fabrics for medical use was a risk that the technicians were keen to avoid.

5.5.4 Creating Different Fabric Weights and Densities
5.5.4.1 Controlling the Weight
At this stage in the research, different fabric weights were achieved by controlling the quantity of fibre fed into the card; the greater the amount of fibre, the heavier the web. The relationship between the weight of fibre fed into the card and the resulting weight of the web was relatively consistent using the Texon equipment as the lapping system meant that the webs were always the same size. This enabled the weight of fibre needed to produce a certain weight of web in terms of gsm² to be calculated. In order to apply a similar working method to the cross lapping systems at the NRGroup and CMRI, the output belt was kept still during operation to enable webs of a predetermined size to be made. When the output belts were activated, the weight of the web was determined by the speed of the input and output belts.
Calendering, heat pressing and needling condensed and compressed the webs, thus impacting upon the density and weight of the resulting fabric.

5.5.4.2 Needling
Because webs were needled, a certain amount of distortion in terms of their shape and size took place. The speed/advance rate of the web through the machine and the depth and extent of needling that took place impacted upon the amount of distortion. In general terms, these parameters affected the extent to which the web was lengthened, shortened and compacted (as discussed later in section 9.5.3.2). This impacted upon the density and weight of the resulting fabric.

At this stage in the research, the technical staff involved advised on suitable parameters for the work. As needle punching was not central to the work at this stage, it did not form a central part of the investigations.

5.5.4.3 Calendering
Calendering the webs also impacted upon the size and density of the resulting fabrics. The extent of compression and distortion appeared to be affected by the gap setting between the rollers; the volume of the initial web; and the direction in which the web was fed into the rollers.

**Gap Setting**
When working at Texon, owing to the ability to change the width of the gap between the two rollers, it was possible to successfully calender a broad range webs of different weights and volumes. The gap was increased for heavier, more voluminous webs. This meant that they were less compressed enabling a greater volume of the web to be retained.

The gap between the calender rollers at the NRGroup was set to the nip point. This meant that the air in heavier, more voluminous webs was pushed out causing the web to lengthen and become very flat and thin as shown in Figure 112 (N10.1). In some instances an uneven surface was also created by the uneven distribution of air in the web. It was noted that through air bonding would be a more suitable method of thermally bonding bulky fabrics.
Layering, Strength and Direction
As discussed in Chapter 2, the way in which the webs are layered impacts upon their strength in both the machine direction and cross directions. The carding equipment at Texon layered the webs in a parallel fashion resulting in webs with a high strength in the machine direction. Therefore, when the webs were fed into the calender in its machine direction there was less distortion in terms of length. The webs that were made at both the NRGroup and CMRI, were cross laid resulting in webs that had a similar degree of strength in the machine and cross directions. Therefore, the direction in which in they were fed into the card had less impact on the extent of distortion that took place.

Heat Pressing
Heat pressing distorted the web's shape and size the least out of the bonding methods used. This was possible due to the static nature of the process. The webs did not move during the bonding process and pressure was applied uniformly across the webs' surface. When voluminous webs were pressed, owing to heat only being applied on one side, fabrics with smooth top surfaces but lumpier bottom surfaces were created.

5.5.5 Manipulating the Handle and Surface Qualities
It was demonstrated in Stage 1 of the work that a number of factors impact on the handle and surface qualities of nonwovens including the type and blend of fibre used, the weight of web, the method of bonding and the bonding parameters (these interactions are discussed by Pourmohammadi (2007, p.300) ). The effect of the various bonding methods and different ratio's of binder fibre on the resulting fabrics is discussed here.
Chapter 5  Practical Research Stage 2

5.5.5.1 Calendering
The calendering process compressed, flattened and consolidated webs. This generally resulted in fabrics with a comparatively smooth surface. The different adjustable parameters within each calendering system impacted upon the degree of compression and consolidation.

**Speed, Pressure and Temperature**
The speed, pressure and temperature at which the webs were bonded affected the handle and quality of the resulting fabrics. The results were similar to those when using the heat press in Stage 1 of the practical research. With regard to the systems used at Texon and the NRGroup, it was observed that the higher the temperature and longer the dwell time, the greater the extent of bonding appeared to be and the stiffer and crisper the fabric. The most effective temperature tested was where both rollers were set at 100°C. The fabrics produced with the NRGroup suggested that the greater the pressure the smoother, flatter and thinner the resulting sample. These qualities are also affected, however, by the fibre type and the amount and position of binder fibre in the web.

**Gap Setting**
The fabrics produced using the system at Texon showed that the smaller the gap between the rollers the more compressed the web. The larger the gap between the rollers, the more voluminous the resulting fabric (T14, T21). The system used at Texon was effective at bonding thin to mid-weight webs but only bonded the outer layers of heavier denser webs. This created almost spongy fabrics in certain instances which could be peeled apart (T22). In contrast to this, the system used at the NRGroup had an un-adjustable nip point that flattened all webs to a similar thickness. The handle of the resulting fabrics was stiff, dense, smooth and paper like. As noted above, the excess air in the heavier and more voluminous webs was forced out by the close nip between the rollers, which resulted in uneven surfaces (N10.1-N10.4). It was found that this effect was reduced when the webs were gently pre-needled to compress and reduce the amount of air in them prior to calendering.

5.5.5.4 Different Ratio's of Binder Fibre
Changing the ratio of binder fibre in the web had the most noticeable impact on the handle and surface quality of the resulting fabrics out of all the parameters observed. The extent of thermal bonding was observed by noting the crispness of handle and the general strength of the fabrics (the observations made were subjective).

The resulting fabrics enabled the researcher to observe that the greater the quantity of binder fibre, the crisper, smoother, stiffer and more plastic like the fabric. With the exception of the
viscose sample, fabrics with a 10% ratio of binder fibre evidenced some thermal bonding and in the most part retained a soft handle and fabric like quality when calendered at 100°C. At this ratio and temperature the viscose web began to take on a more paper or cardboard like quality (C1.1.1). A ratio of 33% binder fibre resulted in fabrics that were much crisper and appeared to be stronger. They also retained the surface texture and general quality of the base fibre (C5.3.2, C1.3.2).

Where a ratio of 50% binder fibre was used fabrics were produced that predominately took on the characteristics of the binder fibre in terms of handle and surface quality. The fabrics had plastic and paper like surface qualities and handle (C1.2.2, C.2.2.2, C.5.2.2). Usually, the characteristics of the base fibre were also less evident; the long ramie fibres and nep in the wool mix fibre were less evident. Raising the ratio of fibre to 66% increased these qualities and caused webs with yarn and fabric pieces embedded within them to pucker, ripple and deform (C1.4.2, C3.2.4.1). This occurred when the webs were pressed at both 85°C and 100°C (C1.4.1). As expected, fabrics pressed at 100°C were more effectively bonded than those calendered at 85°C.

5.5.5.5 Needling
As outlined previously, 'needle punch density' has a substantial impact on the properties of resulting fabrics, in particular surface and handle. Needle punch density is determined by input/output speed advance rate and the number of needles per unit area. In general terms, a large advance rate means that the web is essentially punched less resulting in a softer fabric (Dilo Manual). In contrast a small advance rate essentially means that the web is punched more resulting in a stiffer and more compacted fabric. The depth of punch relates to the depth of entangling that takes place and the type of needle used.

Within this Stage of the research, needling was used to condense and compress webs before thermal bonding to create better quality fabrics, and, to give the webs greater strength prior to bonding, enabling them to be transported more easily. As outlined above, the needling parameters were kept at a constant during the work conducted at Texon and CMRI. During the work conducted at the NRGroup, the effect of the needle punch depth on quality of the fabrics following calendering was observed. Broadly speaking the samples that had been needled before calendering were flatter, smoother and more consistent than those that had not been needled. Thicker and heavier webs still resulted in fabrics with a rippled and lumpy surface after calendering.

For medium to heavy weight webs, small changes in the depth of needle punching had a minimal effect on the qualities of the fabrics produced following calendering. Samples that had been punched at a depth of 10mm were not considerably smoother in surface than those
punched at 8mm or 6mm (N10.1, N10.3 and N10.5). Samples that were more heavily punched (2 and 3.4), for example the Viscose webs produced at CMRI, were more effectively calendered in that the surface was smooth and even rather than lumpy. However, the punch marks were obvious in the surface of these fabrics creating a pocked effect that impacted on both the visual and tactile qualities of the fabrics, as shown in Figure 113.

For lighter and thinner webs, the depth of punching had a subtle effect on the handle and surface quality of the resulting calendered samples. Samples punched at 6mm resulted in fabrics with a softer handle and fluffier surface than those punched at 8mm and 10mm (N6.2, N6.5 and N6.8). A greater depth of punching appeared to result in smoother, stiffer and stronger samples. The extent of punching also seemed to impact upon the extent of distortion that took place during calendering. However, this was not closely studied and measured during this stage of the research.

5.5.5.6 Heat Pressing
Heat pressing webs made using pilot scale equipment resulted in subtly different fabrics than those that were calendered. In particular, the extent to which the fabrics were flattened and compressed was reduced and resulted in fabrics that retained more of the depth and volume of the original web (N10.1, N10.10) and the fabric surfaces were more consistent. As observed in Stage 1, the side of the web nearest to the hot plate resulted in a smoother surface than that against the bed. The temperature and dwell time affected the fabrics in the same way as in Stage 1 and as when using a calendering system to activate thermal bonding. The fabrics did, however, appear to be weaker than those that had been calendered.

5.6 Chapter Summary
The aim of this stage of the practical research was to explore the translation of the design ideas developed using hand-based nonwovens methods to pilot scale industrial nonwovens
machinery. The aim of the work was to identify the opportunities and limitations to manipulate carding technology and thermal bonding technologies that utilise heat and pressure for design purposes. The work focused on the use of a binder fibre in combination with a range of fibre types. In doing this, the intention was to explore the idea of fluidity between craft and industrial production contexts and to establish a mode of practice that could be sustained throughout the remainder of the research to enable design development.

The chapter has described three periods of work that took place in different nonwovens pilot plants. It described the observations regarding the opportunities and limitations that were presented in each situation and the subjective qualities of the fabrics that were produced.

5.6.1 Limitations and Possibilities of Pilot Scale Machinery

In summary, the investigation demonstrated that the design techniques established in the first stage of the investigations could be successfully applied to pilot scale nonwoven machinery. However, it was evident that each pilot line presented different opportunities and limitations that were dependent upon the specific nature of the machinery used at each stage of production.

At the web formation stage, the scale of the carding machinery, the layering mechanisms in place and the opportunity to be experimental with different types and colours of fibres impacted upon: (1) the extent to which composition within the fabric designs could be manipulated; (2) the types of additional materials that could be incorporated into the structure of the webs; and (3) the different surface and colour effects that could be achieved.

At the web bonding stage, the quantity of binder fibres incorporated within the webs and the way in which heat and pressure was applied determined the surface quality of the resulting fabrics.

5.6.2 Fluidity of Practice

Dormer's description of a fluid practice between textile production contexts in relation to woven textiles suggests that fabric designs can be translated from hand-based production to industrial production 'without fuss' (1997, p. 168). In terms of exploring the idea of a 'fluid practice' between craft and industrial production in the area of nonwovens, it became clear during this stage of the research that sampling using pilot scale industrial machinery is an essential intermediary stage between hand-based and industrial production.

During the work, the techniques established and fabrics produced using hand-based nonwovens methods provided a starting point for using the pilot scale machinery. Although the techniques applied to the pilot scale were similar to those employed when using hand-
based methods, the pilot machinery used affected the extent to which these techniques could be successfully implemented and the quality of the resulting fabrics. The resulting fabrics were quite different to those produced using hand-based methods. They were uniform and consistent in contrast to the more organic and inconsistent nature of the hand-made fabrics. It was felt that although the hand-made samples provided a starting point, the difference in the quality of fabrics produced using the pilot scale machinery was superior to those produced using the hand-based methods. This, therefore, pointed to the need to carry out design development work using pilot scale machinery rather than hand-based methods.

5.6.3 Establishing a Sampling Procedure and Sustainable Working Context
From the work conducted it was clear that the opportunities and limitations of the pilot scale machinery were specific to each working situation. This suggested that the results of further research would be context specific. It was felt that, where possible, further work within this research should be carried out using only one of the production lines used already so that the results would be consistent. Owing to the scale and subsequent versatility of the nonwovens line at CMRI, and the willingness of technical staff to be experimental it was felt that this would be the most suitable place in which to conduct further work. The availability of a number of short periods on the line also meant that the work could be effectively planned and carried out. During this period of the work, it became evident that the difficulty and expense involved in accessing pilot scale equipment was one of the most important features in trying to establish a sustainable working context.

In terms of the sampling procedure, from the work produced it was decided that carding, lightly needling and heat pressing proved to be the most effective and consistent way of making fabrics which incorporated different design elements. These methods were taken forward into the next stage of practical work.
6.1 Introduction

The last Chapters explored the translation of the design ideas developed using hand-based nonwovens methods to pilot scale industrial nonwovens machinery. Opportunities and limitations to manipulate carding technology and thermal bonding technologies that utilise heat and pressure for design purposes were confirmed, and the affects of different needling, calendaring and heat pressing parameters and fibre blends on the properties and qualities of the resulting fabrics were subjectively observed and discussed. To further explore the design potential of these fabrics and to move them into new areas, further processing was explored.

6.1.1 Aims and Approach

This Chapter describes a series of investigations into the use of embossing, printing, laser cutting and laser marking as decorative finishing processes for nonwovens. The aim of the work was; firstly to see if the fabrics produced, using the sampling methods described in the previous chapter, could be successfully embossed, printed, and laser cut/marked using crafts based processes; secondly to observe the impact of different fibre types, fibre blends and web forming and bonding parameters on the qualities of the resulting fabrics.

Within the Chapter, initial investigations into each process are outlined and then further sampling work is described. The analysis focuses on the success of each process in relation to specific fabrics and the effects achieved. It does not aim to provide scientific explanations for the observations and reflections made but to document the making process and the results achieved.

This Chapter covers the following areas in connection with each investigation:

- process background;
- materials used;
- sampling methods and equipment;
- observations and reflective analysis of the processes and resulting fabrics.

6.2 Embossing: Initial Investigations

Embossing is used for a number of purposes within the nonwovens industry. The most common process used to emboss nonwovens is hot calendering (Stukenbrock, 2003, p. 414 - 415). As well as being a method of thermal bonding, hot calendering is commonly used as a finishing process for both mechanical and decorative purposes on synthetic fibre webs of up to 50 g/m². Metal rollers engraved with various patterns are used to create specific bonding
points, relief pattern and surface effects. Stukenbrock (2003, p. 415) describes an embossing process called ‘crié’ embossing which involves the use of different heights of engraving to achieve extreme three-dimensional effects. He notes that depending on the engraved pattern, fabrics with either dull lustre or shine are created. The recessed or raised areas of the fabrics are then dyed to enhance their three-dimensional qualities.

Within this stage of the research, initial investigations were carried out into the use of ‘lo-tech’ hand-based embossing methods. The use of a heat transfer press and a papermaking press in conjunction with engraved metal and lino cut plates were explored. Embossing techniques were developed by drawing on traditional papermaking and printing processes and methods used in the nonwovens industry. The materials and sampling methods used are outlined in the sections that follow.

6.2.1 Materials: Fabric selection
A number of the fabrics made during Stage 1 and 2 of the practical research were selected for sampling. The selection was comprised of fabrics made from a range of fibre types and blends and represented a range of fabric weights and surface qualities. The fabrics that were used are documented in Table 13 in Appendix 4.

6.2.2. Sampling Method: Using a Heat Press to Emboss
A heat transfer press was an accessible means of applying heat and pressure to the fabrics and therefore formed an initial focus for exploring embossing. To imbue fabrics with three-dimensional pattern using a heat press, a series of steel and lino embossing plates were made.

Steel and copper, in sheet form, is routinely etched using acid to make plates that have relief surfaces for various types of printing. Acid etching was used to produce embossing plates for use in the heat-press.

6.2.2.1 Acid Etching
A sheet of 1 mm steel and 1.5mm copper were selected as they were a suitable thickness for use in the press. A decorative pattern was printed onto the plates using black bitchemen paste. When the paste had dried, the plates were placed in an acid bath which corroded the unprinted areas of the plate creating a relief surface. The residue metal was removed by lightly wiping the plates intermittently whilst they were in the bath. Further to the steel plates, two lino cut plates were used, that had been engraved by hand using lino cutting tools.
6.2.2.2 Embossing

The following procedure was used to emboss the fabrics: (1) the fabric was placed on the bed of the heat press; (2) the plate was positioned on-top; (3) a piece of release paper was placed on-top; (4) the temperature and dwell time on the heat press were set; (5) once the press had reached the desired temperature the hot plate was lowered and the fabric subjected to heat and pressure for the specified time; (6) the release paper was then removed and the fabric taken from the plate.

The quality of emboss achieved using different temperatures and dwell times was observed. Stuckenbrock (2003, p. 414) suggests that in industrial calender bonding, cylinders are usually set between 20°C and 30°C above the melting point of the binder fibre, therefore the temperatures used in the investigation were higher than those used to bond the original webs. The recommended bonding temperature of binder fibre Wellbond M1440, was between 130°C-190°C, therefore, the temperature was initially set to 150°C. Dwell times varied from 20-60 seconds. The processing details of each sample and the observations made are documented in Table 13 Appendix 4.

6.2.3 Observations and Reflections

Initial observations were made in regard to the affect the following parameters on the quality of emboss achieved; fibre type and blend; fabric construction methods; type of embossing plate and; the dwell time and temperature used.

6.2.3.1 Fibre Type and Blend

Regarding the type of fibre used, the initial trials suggested that fabrics made of textured fibres such as wool (E1.1, E1.8, E1.25), resulted in an embossed pattern with slightly less definition than fabrics made of smoother, shorter fibres such as viscose (E1.2, E1.13) as illustrated in Figure 114. In regard to the viscose fabrics it was noted that fabric surface surrounding the raised areas was flat and smooth which created a greater contrast between the surface and raised areas resulting in a more defined emboss. The initial results also indicated that fabrics that contained greater proportion of binder fibre resulted in a more defined and greater height of emboss (E1.11, E1.2). This is illustrated in Figure 115.
6.2.3.2 Method of Production

The different methods used to produce the fabrics also affected the quality of emboss achieved. As noted in Chapter 5, fabrics that had been produced using pilot scale industrial equipment had smoother and more even surfaces than those produced using hand based equipment (E1.8). Because of this, the quality of emboss achieved was more consistent on the fabrics that had been produced using pilot (E1.11) scale equipment. The results also indicated that the more uniform the fibre blend within the fabrics, the more consistent the quality of emboss (E1.2 and E1.5, E1.3 and E1.4, E1.11). This is illustrated in Figures 116 and 117.

6.2.3.3 Temperature and Dwell Time

The results indicated that the greater the temperature the greater the height and more defined the emboss. (E1.2, E1.13, E1.12). In a similar way, longer dwell times resulted in fabrics with
a greater height of emboss, (E1.13, E1.14). As expected, however, greater temperatures and longer dwell-times resulted in stiffer, harder fabrics.

6.2.3.4 Embossing Plates
The thickness of the embossing plates used and the type of material from which they were made, affected the quality and depth of the embossed pattern that was achieved.

It was anticipated that the thicker copper plate would result in a deeper etched surface than that of the steel plate and therefore a deeper fabric emboss. Although the etched surface was deeper, as illustrated in Figures 118 and 119, the difference between the depths of emboss achieved using the copper plate and steel plate was hardly visible (E1.11, E1.14 and E1.21). Further to this, the fabrics tended to stick more readily to the copper than to the steel, which made it more difficult to peel the fabrics from the surface of the plate and damaged the surface of the fabrics as shown in Figure 123 (E1.15). It was noted that the greater the temperature and dwell time the greater degree to which the fabrics stuck to the plate (E15, E1.18, E1.15 E1.21).

The greatest depth of emboss was achieved using the lino cut plate. The larger size of the etched pattern areas seemed to create more room for the fibres to move which, as illustrated in Figure 120, resulted in a more effective emboss (E1.25, E1.27). However, the lino did not withstand the temperatures required for the process and began to deform whilst in the press. Lower temperatures and dwell times were, therefore, trialled which initially produced poorer results. To try and improve the results achieved at these settings, a light mist of water was introduced to the fabrics before embossing as is sometimes done when embossing paper. As
shown in Figure 121, this improved the quality of emboss achieved (E1.24, E1.25 and E1.26 with E1.27).

Figure 120: Sample E1.25

Figure 121: Sample E1.127

6.2.4 Sampling Method: Using a Paper Press to Emboss
Although using the heat press proved a successful means of embossing the fabrics there were some drawbacks to the process. Subjecting the fabrics to further heat and pressure having already bonded them caused the fabrics to become quite stiff. Further to this, the process deformed the lino embossing plates. Alternative methods of embossing the fabrics were therefore explored. It was considered that the similarities between paper and nonwovens in terms of structure and quality might make the processes that are used to emboss paper applicable to nonwovens.

6.2.4.1 Embossing Plates
Due to the success of the lino plate in the previous investigation a further lino plate was made. Due to time limitations, rather than engraving the plate by hand it was laser cut.

6.2.4.2 Sampling Procedure
The fabrics were embossed in a papermaking press using the following procedure; (1) the fabrics were dampened; (2) placed on-top of the lino plate and placed between layers of paper and papermaker’s felt in the press; (3) pressure was then applied by lowering the top bed and; (4) when the pressure was released the fabric was removed.
6.2.5 Observations and Reflections
Owing to the longer fibre lengths within the fabric and thickness of the fabric using the paper making press to emboss the fabrics was not as effective as had been hoped. An initial emboss was created in each of the fabrics. This was temporary, however, lasting only a few minutes. As the fabrics relaxed and dried the emboss ‘fell out’. This was particularly evident in fabrics made of fibres with high elastic recovery such as wool. The inability of the fabrics to hold a three dimensional shape without the use of heat may have been further due to the more open flexible structure of the nonwovens in comparison to paper.

6.3 Embossing: Process Parameter Investigations
The initial embossing investigations showed that using a heat transfer press was a viable means of embossing nonwovens made from various fibre types that contained a portion of thermoplastic fibre. In order to get a better understanding this process, in particular the impact of different fabric production parameters and embossing parameters on the quality of the emboss achieved, a further period of sampling was conducted. The materials and sampling methods used are outlined in sections 6.3.1 and 6.3.2 respectively.

6.3.1 Materials
In order to enable more focus within the work, two fibre types alongside the binder fibre (Wellman M1440) were selected for use in the investigation. Viscose and ramie were selected as they were quite different in terms of their qualities and properties and the nonwovens that had been produced using these fibres were quite distinct. The details of these fibres are given in Table 1 and Table 2.

6.3.2 Sampling Method
6.3.2.1 Fabric Construction
The sampling procedures used was based on those established in Stage 2 of the practical research.

Carding and Needling
At this point in the research, due to company re-organisation, Texon had kindly donated a number of pieces of their nonwoven sampling equipment to the School of Art and Design at Loughborough University where a nonwovens sampling lab was established. This equipment was, therefore used during this stage of the research. The heat transfer press that had been previously used was also employed.
A series of samples were made using different needling and thermal bonding parameters. The initial parameters employed were based on those used during stage 1 and 2 of the work. These parameters were varied to enable their affect on embossing to be observed. The details of the parameters used are given in Tables 14-17 in Appendix 4.

The same weight and size of web was produced for each sample. The blend of binder and main fibre was kept constant at 70% main fibre 30% binder fibre. In regard to needling, the needle depth and advance rate were varied. The number of strokes per minute was kept constant at 150. Some webs were needled on one side and others on both. In varying these parameters the intention was to create fabrics of different densities, weights and levels of fibre entanglement. A further set of ramie samples were made in which the needling parameters were kept the same but the ratio of binder fibre altered. Details of each fabric are given in Table 16 in Appendix 4.

The fabric weight per metre square (g/s/m²) of each sample was calculated by weighing and measuring the fabrics after needling and the thickness of each sample was measured before thermal bonding.

**Thermal Bonding**

Following needling, the fabrics were thermally bonded in the heat press prior to embossing. Because the fabrics would in effect be re-bonded in the embossing process, a low temperature (100°C) and dwell time (10 seconds) was used to minimise fabric stiffening. The effect of thermally bonding on one or both sides prior to embossing was observed as was the effect of not thermally bonding prior to embossing. The details of each sample made are given in Table 15 and 17 in Appendix 4.

6.3.2.2 Embossing

In light of the initial embossing trials a 1.5mm laser cut steel plate was made for use in this investigation. It was anticipated that a deeper emboss would be achieved by cutting through the metal rather than etching into its surface. Steel was selected over lino due to its greater durability within the process. The cut out metal pieces were also used as a means of negative/positive embossing. Both floral and geometric patterns were cut into a sample plate.

Following thermal bonding each sample was embossed using the procedure outlined in section 6.2.2.2. Certain fabrics were wetted before embossing using a fine cold-water mist. Fabrics were initially embossed at low temperatures and subsequently between temperatures of 100°C and 180°C. The dwell time was initially set at 10 seconds and then times between 10-60 seconds were used. Processing details for each sample are shown in Table 15, 16 and 17 in Appendix 4.
Chapter 6

Observing the Impact of Needling Parameters

The samples that had been produced using different needling parameters were embossed to observe if there was any differences in the quality of emboss obtained. The samples were thermally bonded at a) 100°C for 10 seconds (pressed once) and b) 100°C for 10 seconds (pressed twice) before embossing. Each sample was then wetted and embossed with the cut steel plate at 150°C for 10 seconds. The details for each sample are given in Table 17 in Appendix 4.

6.3.3 Observations and Reflections

Observations were made in relation to the affect of the fabric construction and embossing parameters on the quality of emboss achieved.

6.3.3.1 Different Needling Parameters

Webs that were needled at different advance rates and at different needle depths resulted in fabrics with subtly different qualities in terms of handle and consistency, and a subtly different quality of emboss. Those that had been needled at a greater depth (10mm) or that had been needled on both sides, were more compacted than those that had been needled to a lesser extent (E2.1, E2.2, E2.3). Following thermal bonding and embossing, the resulting fabrics had smoother surfaces and a crisper emboss (E2.5, E2.6, E2.7, E2.8) as illustrated in Figures 122 and 123. Links between different advance rates and the quality of emboss achieved were less clear.

Figure 122: Sample E2.1

Figure 123: Sample E2.4
6.3.3.2 Thermal Bonding Parameters

The thermal bonding parameters also appeared to affect the quality of emboss. When the ratio of binder fibre remained constant, the fabrics that had been bonded on both sides before embossing resulted in a smoother surface, a slightly more defined emboss but a stiffer fabric handle (E2.1.1b and E2.2.1b) than those that had only been pressed once (E2.1.1a and E2.2.1a). When the quantity of binder fibre was increased this pattern of results did not remain the same. When fabrics were not thermally bonded before embossing, a clear emboss was not achieved, as shown in Figure 125. This may have been due to the low temperature used or the failure of the embossing plate to conduct enough heat (E2.18.1a, E.2.18.1b, E2.18.1c).

6.3.3.3 Fibre Blend

The quantity of binder fibre within the fabrics had a subtle effect on the quality of emboss achieved. At the initial embossing settings of 100°C for 10 seconds, all of the fabrics that had been thermally bonded before embossing retained, to a greater or lesser extent, three-dimensional pattern. Fabrics with 30% and 50% binder fibre produced the clearest emboss (E2.16 and E2.17). Fabrics with only 10% binder achieved a relatively weak three-dimensional pattern (E2.15). Similarly, fabrics with 70% bi-component did not achieve a consistent emboss (E2.18). This is illustrated in Figures 124-125.

6.3.3.4 Embossing Parameters

Both the cut metal plate and the metal pieces resulted in an evident three-dimensional pattern on certain fabrics. The temperature and dwell time at which the fabrics were embossed; parameters affected the quality of emboss that was achieved.
Chapter 6 Practical Research Stage 3

Temperature and Dwell Time

At temperature 100°C, as the dwell time was increased the samples generally became stiffer and smoother and the emboss became slightly more defined (E2.16.3–E2.16.5 and E2.17.3–E2.17.5). When the dwell time was increased to 60 seconds, however, yellowing began to occur on the surface of the fabrics (E2.16.5), as shown in Figure 126. As the temperature was increased to 150°C and the dwell time kept constant at 10 seconds, the embossed pattern achieved was defined but no yellowing occurred (E2.16.6), as shown in Figure 127. As shown in Figure 128, at 180°C, the samples became stiffer and harder, but the definition and height of emboss did not increase but remained at a similar level to the embossed pattern achieved at 150°C (E2.16.10). The optimum embossing parameters were identified, subjectively, to be temperature 150°C and dwell time 10 seconds.

6.3.4 Embossing Summary

In summary, the results of this stage of the research demonstrated that the nonwovens developed using pilot scale equipment could be effectively embossed using a heat transfer press in conjunction with a metal or lino embossing plate. The work suggested that metal plates were the most durable and, that laser cut metal plates potentially enable a greater depth of relief than acid etching in the subsequent emboss.

The results show that different fabric construction parameters (fibre blend, needling depth, temperature and dwell time) have a subtle impact on the quality of emboss achieved. The results suggest that the greater the extent of needling and the more consistent the thermal bonding (i.e. both sides pressed) the better the quality of the embossed pattern. Fabrics with 10% bi-component resulted in a less defined emboss than those with 30%, 50% and 70% bi-component. There was little difference between the quality of emboss obtained by the latter three quantities.
In terms of the embossing process itself the results show that when the temperature is set above the melting point of binder fibre (i.e. 150°C) an embossed pattern was consistently achieved. It was noted that when the temperature was raised above this to 180°C the quality of emboss was not increased but the fabrics became stiffer. It was also observed that increasing dwell time increased the quality of emboss but at a certain point the fabrics began to yellow.

6.4 Printing: Initial Investigations

The increasing use of nonwovens within both fashion and interiors has led to a greater use of printing and dying for decorative and design purposes within the nonwoven's industry. Stuckenbrock (2003, p425) notes that light and heavy weight nonwovens made from a range of fibre types are routinely printed using conventional textile printing techniques such as screen printing and rotary screen. As in conventional textile printing, dyestuffs and printing pastes appropriate to the fibre type of the fabric are used and appropriate steaming and washing processes are employed to fix the print. Stückenbrock (2003, p.425) suggests that when such methods are used it is preferable that the nonwoven is made of a single fibre type. He notes pigment printing plays an important role as the process can be used on any fibre or blend of fibres and does not require a steaming and washing process but is essentially fixed by dry heat. Heat transfer printing, a method which involves the transference of dye from a release paper onto synthetic fabric under the influence of heat and pressure, is also used within the nonwovens industry, as is digital ink jet printing.

Within this research, initial investigations were carried out into the potential to use studio-based methods to print nonwovens. Techniques explored include; screen printing (conventional dyestuffs and pigment), heat transfer printing, flocking, foiling and devoré techniques. Nonwovens made in stage two of the work formed the focus for initial investigations.

6.4.1 Materials

Fabrics made during Stage 2 were used for the initial investigations. The samples chosen for each investigation are indicated in Tables 18-21 in Appendix 6.

6.4.2 Sampling Method: Screen Printing using Acrylic Pigment

Pigment printing was trialled first owing to its documented ease of use in regard to nonwovens (Stückenbrock 2003, p. 426).
A floral design was exposed onto a printing screen and the following printing procedure was followed; (1) the fabrics were placed onto a backing cloth and secured; (2) the fabric was printed using a paste comprising of between 3%-4% acrylic pigment the remainder Ecotex binder; (3) when dry, the fabrics were placed between two sheets of release paper and pressed in the heat transfer press at 120°C to fix.

6.4.3 Observations and Reflections
As expected, the fabrics chosen were successfully printed using the method outlined. As one would have anticipated, however, the fixing process considerably stiffened the fabrics.

6.4.4 Sampling Method: Printing using Procion and Acid Dyes
Stöckenbrock (2003, p.425) explains that conventional screen-printing methods are routinely used to print nonwovens usually made of a single fibre type. The aim of this investigation was to explore the use of these methods on nonwovens made from a range of fibre types blended in various ratios with a binder fibre. A number of needled webs were selected from Stage 2 of the research for use in the investigation. The samples selected are indicated in brackets in Table 18 in Appendix 4.

The needled webs were thermally bonded in the heat transfer press before printing at 130°C for 10 seconds on one side. All samples were printed on the side that had been bonded in the heat press.

A geometric design was exposed onto a printing screen. The fabrics were printed using the following procedure; (1) the fabrics were placed onto a backing cloth and secured; (2) viscose and ramie based fabrics were printed with a 1% procian dye paste left to dry; (3) the fabrics were then steamed for 15 minutes; (4) wool and silk based fabrics were printed with a 1% acid dye paste and left to dry; (5) the fabrics were then steamed for 45 minutes; and (6) rinsed under a high flow of cold and warm water to remove print paste binders and residue dye. The processing details for each sample are documented in Table 18 in Appendix 4 and the print paste recipes are documented in Appendix 2.

6.4.5 Observations and Reflections
Most of the fabrics were successfully printed, however, the printing process was not as straight forward as when printing conventional fabrics. On certain occasions some of the fabrics stuck to the surface of the screen following printing which meant that the fabrics had to be delicately peeled from the screen and returned to the table to dry. This was more problematic with lighter and weaker fabrics as they were more difficult to handle. However,
because the process was hand-based, this could be carefully controlled and when the fabrics were handled carefully the quality of the print achieved was not affected. Stückenbrock (2003, p.425) identifies similar difficulties when printing nonwovens in an industrial context. In regard to lightweight nonwovens, he notes that the problem is overcome by controlling and adjusting surface tension and in the case of heavier needle-punched nonwovens, greater dimensional stability is achieved by needling a stable backing fabric to the nonwoven prior to printing.

6.4.5.1 Fabric Construction
The results suggest that the quality of the print achieved was affected by a number of the fabric production parameters including the quantity of binder fibre in the fabric and the extent of needling and thermal bonding before printing.

**Fibre Blend**
The results suggested that, in regard to the quantity of binder fibre in the fabric, as expected, the greater the quantity of binder fibre in the fabric the less the up-take of dye on the fabric and the less vibrant the print. This is illustrated in Figures 129 and 130 (P2.1.4 and P2.1.6). This occurred because the dye in the print paste was selected for its affinity to the base fibre rather than the binder fibre. Further to this, some of the samples had an uneven uptake of dye across the surface of the fabric (P2.1.8), which was most likely due to an uneven blend or melt flow of binder fibre within the fabric.
The quantity of binder fibre in the fabric also affected the impact that the steaming process had on the quality of the resulting printed fabric. Owing to the heat involved in steaming, the process had a stiffening affect on the fabrics. Stiffening was greater in fabrics that contained a greater ratio of binder fibre and in those fabrics printed with an acid dye as they required a longer steam time. As illustrated in Figure 131 (P2.1.14) the fabrics containing greater binder fibre started to curl under the influence of heat, which distorted and 'cracked' the print.

Owing to their comparative weakness, lightweight fabrics containing relatively small amounts of binder fibre began to break down during the rinsing (or 'washing off') process as illustrated in Figure 132 (P2.3.1).

Additional Materials

Some interesting effects were achieved in fabrics that had additional fibre, fabric or yarns embedded within their surfaces. As illustrated in Figure 133, dependent on the type of fibre, fabric or yarn in the web, additional materials had a greater or lesser affinity to the dyestuff than the base fibre. Where the additional materials had been printed, an interesting contrast between surface and pattern was created, the additional fibre appeared to be 'highlighted' within the fabric by the colour they took on (P2.1.17 and P2.1.2).
Needling

The results suggested that the impact of needling on the surface quality and strength of the nonwoven affected the quality of the subsequent print. As noted previously, heavy needling before thermal bonding resulted in a textured surface which resulted in a more textured print. In contrast samples that had been needled to a lesser extent before thermal bonding resulted in a smoother surface and smoother print. Both effects were interesting from an aesthetic perspective.

At the washing off stage, samples that had not been needled prior to thermal bonding began to break down during the washing off process because of their lower level of strength (P2.1.18) and the fabrics took on a slightly worn quality.

6.4.6 Sampling Method: Flocking and Foiling

Flocking and foiling processes enable shiny or pile-like surface qualities to be achieved within textile prints. To achieve flocking and foiling, an adhesive substance has to be printed onto the fabric in question. When the adhesive has dried to a ‘tacky’ state, a sheet of flocking paper or foil is placed on top of the fabric. The fabric, with flocking paper or foil on top, is subjected to heat and pressure, often using a heat transfer press set to a given temperature and dwell time (conventional textiles are usually pressed at 180°C for 60 seconds). The heat and pressure cause the flock or foil to transfer and stick to the fabric in the areas printed with adhesive.
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Within this investigation, the possibility of using this process on nonwovens made from a range of fibres blended with different ratios of binder fibre was explored. A range of nonwoven samples was again selected from those developed in Stage 2 of the research. The fabrics used are indicated in Tables 19 and 20 in Appendix 4.

Owing to the relatively high temperatures needed for the flocking and foiling process, each sample was thermally bonded at 100°C for 10 seconds before printing to give the webs enough stability to be printed with adhesive whilst avoiding the stiffening that might occur if the fabric were pressed at a higher temperature.

Two decorative designs were exposed onto screens for used in this investigation. The flocking and foiling procedure used was as follows; (1) the fabric was secured to a backing cloth; (2) a PVA adhesive paste printed onto the fabrics; (3) the fabrics were placed between release paper and pressed in the heat press at 180°C for a) 10 seconds and b) 20 seconds; the fabrics were then removed from the press. The two dwell times were used to enable the degree of flocking and foiling achieved alongside the degree of occurrence of fabric stiffening to be observed. The flocking details are given in Table 19 and the foiling details in Table 20 in Appendix 4.

6.4.7 Observations and Reflections

6.4.7.1 Transfer of Extra Flock and Foil

Both the flocking and foiling processes were successful in that the fibres and foil were transferred onto the areas of nonwoven that had been printed with adhesive. However, fibres and foil were also transferred to the adhesive free areas of the fabric due to the presence of the binder fibre in the fabrics. As illustrated in Figures 134 and 135, the results show that the greater the ratio of binder fibre in the fabric the more dense the covering of flock fibres and foil on the surface of the fabric (FL1a, FL3a, FO1, FO2). The results suggest that the density of covering increases when the dwell time is increased (FL2a and FL2b), as illustrated in Figures 136 and 137. In terms of flocking, this extra transfer created almost ‘dirty’ looking surfaces and in some cases obscured the actual print (FL12 b). However, given the right colour of background surface and flocking fibres the process could potentially be used as a design effect. As shown in Figures 138 and 139, in terms of foiling, the extra transfer of foil resulted in an interesting textured effect (FO2) and gave an almost rubbery finish to the fabrics. These effects could potentially be taken further as a design effect.
6.4.7.2 Fabric Stiffening

As anticipated the high temperatures required in flocking and foiling processes did cause the fabrics to stiffen considerably, including those containing relatively small ratios of binder fibre and those exposed to heat and pressure for the shorter dwell time of 10 seconds. Reducing the temperature and time beyond the settings tested would mean that the flocking process may not work at all. Further to this, the results suggest that if it were to work, fibres and foil would still be transferred to both printed and unprinted areas of the sample. However, If the effects created by the extra fibre and foil transfer and extra stiffening were built into the fabric design the processes could be taken further.
6.4.8 Sampling Method: Devoré

Devoré or ‘burn-out technique’ is a process used to produce pattern on a fabric by printing with a substance that will destroy one or more of the fibres present in the fabric (Wells, 1997, p. 186). The technique is usually used on fabrics that contain a portion of cellulose fibre. A paste, which employs chemicals that release an acid when heated to high temperature, is printed on to the fabric. Wells notes (1997, p. 166) that Aluminium sulphate or sodium hydrogen sulphate are often used. When heated, the cellulose fibres are destroyed by the acid and are removed from the fabric by washing which leaves the printed areas of fabric sheer.

Within this investigation the possibility of using devoré on nonwovens made from cellulose base fibres with different ratio's of thermoplastic binder fibre was explored. At this stage in the work a range of needled webs from Stage 2 of the research were selected. The samples used are indicated in Table 21 in Appendix 4.

Owing to the high temperatures needed for devoré the needled samples were thermally bonded at 100°C for 10 seconds before printing. The fabrics were then printed using the following procedure; (1) the fabrics were attached to a backing cloth; (2) they were printed with devoré paste (the heavier the fabric the more paste applied and left to dry; (3) once the paste was dry, the fabrics were placed between two sheets of release paper and pressed in the heat press for number of short periods; (4) the fabric was inspected frequently and was removed as soon as the fibres had been burnt (this was indicated by the paste turning ‘tea’ like in colour); (5) the fabrics were then submerged in cold water, gently rinsed and the burnt areas carefully rubbed to remove the destroyed fibres.

Initially, the press was set at 100°C as it was hoped that this would enable the original handle of the fabrics to be retained. However, it soon became evident that temperatures greater than or equal to 150°C were needed to effectively burn out the fibres.

The effectiveness of the process on each of the samples was observed. The processing details for each sample and the observations made are recorded in Table 21 in Appendix 4.

6.4.9 Observations and Reflections

The devoré process was successful in that the cellulose fibres within the areas of the fabrics that had been printed with devoré paste were removed. The effects achieved were dependent upon the weight, density and structural integrity of the fabric and the fibre blend within the fabric.
6.4.9.1 Light Weight Fabrics

Lighter weight fabrics were impacted negatively by the rinsing and rubbing required within the devoré process, in particular fabrics that had less binder fibre within them. These fabrics were too delicate to withstand the rinsing and rubbing processes and lost much of their structural integrity. By working with much care, however, it was possible to rinse and rub the fabrics without destroying them. The fabrics produced had an almost lace-like quality. Due to the low proportion of non-cellulose fibre (binder fibre) in these fabrics, almost 'clean' holes were created as illustrated in Figure 140 (D1). Devoré printing lightweight fabrics that contained greater amounts of non-cellulose fibre (binder fibre), resulted in sheer pattern, as illustrated in Figure 141 and 142, in which a fine web of binder fibre remained where the devoré paste was printed (D2 and D4).

![Figure 140: Sample D1](image)
![Figure 141: Sample D2](image)
![Figure 142: Sample D4](image)

6.4.9.2 Medium Weight to Heavy Weight Fabrics

The devoré process produced an 'etched' effect on the surface of heavier fabrics. A relief effect rather than sheer pattern was created. When the fabrics were held to the light, the burnt out areas were translucent creating an interesting visual effect. Both effects were visually stronger when the base fibre and binder fibre were contrasting in terms of texture or colour as illustrated in Figure 143 (D9-D12). As illustrated in Figure 144, additional materials that had been embedded between layers of fibre in certain fabrics were revealed in the devoré printed areas which created further interesting surface effects (D6 and D8). The results suggest that the depth of 'etch' achieved was determined, to some extent, by quantity of non-cellulose fibre (binder fibre) in the fabrics. The greater the ratio of cellulose fibre to binder fibre the greater the depth of 'etch' as illustrated in Figure 145 (D1- D4). Less depth was achieved in those fabrics with a greater proportion of binder fibre and in addition to this, more yellowing occurred in the printed areas of these as shown in Figure 146 (D12) .
The heavier fabrics withstood the washing process more successfully than the lighter fabrics but their surface quality was somewhat degraded by the rinsing and rubbing action and appeared creased and worn. This suggested the need for further finishing in order restore their original surface qualities.
6.5 Printing: Process Parameter Investigations

The initial printing investigations showed that it was possible to print, flock, foil and devoré nonwovens made from a range of fibre types blended with a binder fibre. The results show that the effects achieved by applying these processes to nonwovens are distinct from those achieved on traditional fabrics; particularly those achieved using the devoré process. As highlighted previously, traditional printing processes are commonly used within the nonwovens industry to apply colour and pattern to nonwovens. The use of devoré on nonwovens, however, is less common. It was therefore proposed that further investigations into the use of the devoré process on needled and thermally bonded nonwovens made from different fibre types and blends would form an original contribution to knowledge in this area.

As in the embossing investigations, it was proposed that a greater understanding of the affect of various fabric construction parameters on the success of the devoré process would be beneficial. It was also proposed that by adapting certain aspects of the devoré procedure, a wider range of fabric weights could be successfully processed.

To do this the samples that had been previously constructed for the embossing process using different needling and thermal bonding parameters were employed.

The washing off and finishing processes were explored and adapted in order to enable lighter weight fabrics to be processed successfully and to ensure that the surface quality of the fabrics remained intact.

6.5.1 Materials

The samples used were made from ramie and viscose respectively and contained different ratios of base to binder fibre. The heavier weight fabrics were used because it was the 'etched' effect achieved on these fabrics that was of interest. Details of each sample are recorded in Table 22.1 in Appendix 4.

6.5.2 Sampling Method

Following carding, the fabrics were needled and thermally bonded to different extents. The details for each fabric are included in Table 22.1 in Appendix 4.

6.5.2.2 Devoré Printing

Each fabric was then printed with devoré paste using the procedure outlined in section 6.4.8. The samples were pressed in the heat transfer press at 150°C in order to effectively activate the devoré paste.
6.5.2.3 Adapting the Washing off Process

Following printing and pressing the fabrics were washed off using a gentler approach than rinsing and rubbing. Rather than being submerged in a bucket of running water, the fabrics were placed into a large resin bath of water which allowed the fabrics to be kept flat.

Gentle running water, via a hose, and a small paintbrush were then used to rub away the destroyed cellulose fibres. This meant that rubbing was limited to the printed areas only, minimising disruption to other areas of the fabric surface.

To aid the drying process and to minimise the need for ringing out, drip or spin drying, certain fabrics were pressed using a high pressure press which is normally used in the papermaking processes to squeeze excess water out of sheets of paper pulp.

6.5.2.4 Adapting the Extent of Thermal Bonding and Drying Procedure

A series of trials were carried out which observed; (1) the affect of adapting the extent of thermal bonding prior to devoré printing and (2) the affect of adapting the drying process. The impact of each adaptation on the eventual visual and tactile qualities of the resulting fabrics and the quality of 'etch' effect were observed and documented. Each trial is outlined below.

**Trial 1**

Samples of each needled web were thermally bonded on one side only and then printed with devoré paste on the bonded side, burnt and washed off using the procedure outlined in section 6.5.2.3. The samples were then pegged on a line and left to drip dry. The processing details of each sample are given in Table 22.1 in Appendix 4.

**Trial 2**

The same process was carried out again but the fabrics were printed on the un-bonded side to observe whether this affected the quality of resulting samples and 'etched' effect. The details of each sample and comparisons that were made with the samples produced in Trial 1 given in Table 22.2 in Appendix 4.

**Trial 3**

Trial 3 was the same as Trial 1 but the samples were dried using the assistance of the papermakers press. Once washed off, the samples were placed between two pieces of sheer synthetic fabric and then between papermaker felt and pressed. The details of each sample are given in Tables 22.3 in Appendix 4.
Trial 4

Trial 4 was the same as Trial 2 but the samples were dried using the assistance of the papermakers press as in Trial 3. The details of each sample are given in Table 22.4 in Appendix 4.

Trial 5

In trial five, the process was different in that the fabrics were bonded on both sides prior to printing. The washing off process was carried out as described above and the fabrics were pressed in the paper maker press to aid drying. The details of each sample and comparative observations made with trials 1-4 are given in Table 22.5 in Appendix 4.

Trial 6

The sixth trial focused on devoré printing fabrics with different quantities of bi-component in them in conjunction with the adapted washing off and drying processes. The samples were heat pressed once and printed on their bonded side. Once dry the destroyed cellulose fibres were washed off using the adapted process and were pressed in the papermakers press to aid drying. The details of each sample are given in Table 22.6 in Appendix 4.

6.5.3 Observations and Reflections

The observations made during and after the work showed that the needling and thermal bonding parameters, ratio of binder fibre in the fabrics and adapted washing and drying process all had some effect on the quality of 'etch' achieved through devoré printing.

6.5.3.1 Needling Parameters

The results suggested that the needling parameters had a subtle effect on the depth of etch and surface quality achieved following the devoré process. In regard to the viscose fabrics, it is suggested that the greater the degree of needling the better the surface quality of the final devoré fabric, as shown in Figure 147 (DT1k and DT1m). The samples that had been needled to a lesser extent were less consolidated, resulting in more fragile fabrics that were subsequently damaged more in the devoré process which resulted in fabrics with a poor surface quality as shown in Figure 148 (DT1n and DT1h). In regard to the depth of etch achieved, the difference between the viscose samples that had been needled to different extents were only subtle. The etched lines and marks were, however, clearer and more defined on those samples that had a better original surface quality.
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The ramie fabrics seemed to respond slightly differently to the devoré process than the viscose fabrics. The results suggested that when the extent of needling was greater the depth of etch was slightly shallower and the surface quality less good. This may have been because the ramie fibres were longer than the viscose fibres and therefore more firmly entangled in the fabric, thus requiring a greater amount of rubbing to remove them from the fabric in the washing off process which resulted in a lower quality of etch and surface.

Figure 147: Sample DT1k  
Figure 148: Sample DT1n

6.5.3.2 Printing on Thermally Bonded and Un-Bonded Fabric Surfaces

Printing the devoré paste onto the un-bonded side of the needled webs seemed to have a subtle effect on the quality of the devoré achieved. Both the viscose and ramie fabrics appeared to have a slightly deeper and more defined etch than when the paste had been printed on the bonded side (DT4a–DT4f and DT5a - DT5f). This may have been because the devoré paste could penetrate more easily. In contradiction to these observations, however, the results of Trial 5 suggested that bonding the fabrics on both sides prior to the devoré process resulted in fabrics with better and more consistent surfaces qualities, resulting in more defined and consistent etched marks (DT5a–DT5f and DT5g–DT5m). Figures 149-151 show examples of the fabrics in question.
6.5.3.3 Pressing to Aid Drying

Samples that were pressed in the papermakers press to aid drying resulted, on the whole, in a smoother and more consistent surface quality in comparison to those that had been left to drip dry. This was especially evident in regard to the ramie fabrics. In terms of depth of etch, pressing the samples in this way slightly flattened the relief effect achieved. Broadly speaking, this resulted in a shallower but more defined etch.

6.5.3.4 Different Ratio's of Binder Fibre

Fabrics containing less binder fibre were, on the whole, easier to devoré. The process was more effective due to the greater amount of cellulose fibre within the fabrics and therefore a greater depth of etch was achieved. As the ratio of binder fibre increased, the devoré process had less impact on the fabric surface and the resulting fabrics had a shallower depth of etch. Further to this, as the quantity of binder fibre increased, the surface of the printed areas became discoloured where fibres had been burnt but not successfully removed as shown in Figure 152 (DT6r).
6.5.6 Printing Summary

The initial printing investigations demonstrated that it was possible to print, flock, foil and devoré nonwovens made from a range of fibre types blended with a binder fibre. The results show that the effects achieved by applying these processes to nonwovens are distinct from those achieved on traditional fabrics; particularly those achieved using the devoré process. Further investigations showed that different fabric construction parameters impact upon the quality of devoré fabric achieved. The adaptations made to the traditional devoré procedure drew on papermaking processes and enabled a wider range of nonwoven fabrics to be successfully devoréd. The processes and materials used in this stage of the work show the potential for much design development and form the basis of an original contribution to knowledge.

6.6 Laser Cutting and Marking: Initial Investigations

In recent years, laser cutting has become increasingly used in the textile industry within commercial manufacturing and craft spheres manufacturing. They are also used within the nonwovens industry. Rödel (2003. p 474 -477) explains that lasers are often used to cut nonwovens into interlining pieces. He notes that when producing comparatively small numbers of pieces, laser cutting provides an economical alternative to traditional cutting methods. As noted in Chapter 2, in couture fashion, laser cutting has been used to intricately cut nonwovens such as Tyvek for decorative purposes. Within one-off production contexts such as this, laser cutting is normally perceived as an expensive process. However, the effects achieved often add decorative and design value to the products in question.
Powell (1998, p.1) summarises the CO2 laser cutting process. He explains that a high intensity beam of infrared light is generated by a laser. The beam is focused onto the surface of the material to be cut by means of a lens. The focused beam heats the material and establishes a localised ‘melt’ through the depth of the material. The molten material is ejected from the area by a pressurised gas. This process of material removal moves across the surface and creates a cut. As well as to cut, laser technology can be used to mark or engrave materials and bond or weld materials.

In regard to decoratively cut nonwovens, it appears most of the work to date using lasers has been conducted on synthetic material. Within this research, the initial work using lasers explored the potential to cut and mark nonwovens made from a range of natural fibres blended with a thermoplastic binder fibre. The aim of the work was firstly to see if the fabrics produced were appropriate for laser work and secondly, to observe the affect of different fibre types, blends and fabric weights on the quality of cut or mark achieved.

Due to the negative environmental implications of devoré, a further aim of this period of work was to establish an alternative means of creating an etched surface effect.

6.6.1 Materials

Nonwovens made during Stage 2 of the work were used in the initial investigations. The fabrics used are indicated in Table 23 in Appendix 4.

6.6.2 Sampling Method: Laser cutting

Initial cutting trials were carried out with a company called GS UK. A morning was spent with the company cutting the fabrics. The work was carried out using their FB730 laser cutter. A series of samples were cut with a circle motif at standard speed and power settings. Observations were made relating to how each fabric reacted to the cutting process. Details of the samples cut and observations made are given in Table 23 in Appendix 4.

6.6.3 Observations and Reflections

When cut at standard settings, the majority of the fabrics were cut cleanly but all were left with prominent singe marks on the cut edges. The nature and degree of singeing differed depending on the fibre content and thickness of the fabric. Fabrics containing natural fibres were more severely singed, in particular fabrics containing wool, as shown in Figure 153 (LC6, LC2). As shown in Figure 154, a greater extent of singeing was evident on thicker bulkier fabrics (LC7) than on thin lightweight fabrics as shown in Figure 155 (LC8). Further to
this, a haloing effect was evident on a number of fabrics in which the singe appeared to spread out from the cut edge, as shown in Figure 153.

It was suggested by technicians at GS UK that the degree of singeing could be greatly reduced by specifically adjusting the speed and power of the laser for each fabric. Further to this, it was noted that adjusting the fibre blends specifically for laser cutting might result in less singeing and a cleaner cut. Adjusted laser speed and power were explored in later investigations and is discussed in section 6.7. The effects achieved when cutting fabrics made from different fibre blends were also explored.

### 6.6.4 Sampling Method: Laser Marking

Initial laser marking trials were also carried out with GS UK using the FB730. The machine had a raster capability enabling fabrics to be marked as well as cut. In order to mark the fabrics a Bitmap file of the image to be used was made. A series of samples were marked with a simple floral motif using standard settings. This essentially etched the surface of the fabric, as shown in Figures 156 and 158. Observations relating to how each fabric reacted to the process were made. Details of the samples marked and observations made are given in Table 24 in Appendix 4.

A number of the different types of web were bonded together in the heat transfer press to create layered fabrics before applying the laser marking process. It was hoped that the marking process would etch away the top layer to reveal the bottom layer. Some of the fabrics were subjected to the same washing off process used in the devoré investigations.
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Again, observations relating to how the fabrics responded to the process were made. Processing details and the observations are documented in Table 24 in Appendix 4.

6.6.5 Observations and Reflections

All of the samples were successfully laser marked in that the selected motif was etched onto the surface of each fabric. However, as with laser cutting, all of the fabrics were visibly singed to a greater or lesser extent. The results suggested that the extent and nature of this singeing was again dependent on the fibre content and weight of the fabric. Samples with a greater degree of binder fibre in them tended to result in etched areas that had the appearance of droplets on the surface as shown in Figure 156 (LM1, LM4). As illustrated in Figure 158, fabrics made of ramie and viscose resulted in completely singed etched areas (LM2).

6.6.5.1 Washing-off

To remove the burnt fibres following the laser marking process, samples of each fabric were washed using the washing off process used outlined in section 6.5.2.3. The singed fibres were removed from the surface of certain fabrics leaving a clean etched area as shown in Figure 158 and Figure 159 (LM2 and LM5b). On others, harder rubbing was required to remove the fibres resulting in rough/spoilit surfaces in the etched areas, as shown in Figure 160 (LM3). It was also difficult to remove the burnt fibres from around the edges of the etched motifs. Where the mark had penetrated a number of fibre layers, the embedded materials in some of the fabrics were also burnt as shown in Figure 161 (LM5). Again, this was difficult to wash off and remove and left visibly singed areas on the surface of the fabric.
6.7 Laser Cutting and Marking: Further Investigations
The initial investigations into laser cutting suggested that further investigations into appropriate laser settings for the nonwovens in question would be beneficial in enabling a better quality cut to be achieved. The initial investigations into laser marking as a fabric etching technique and as an alternative to the devoré process also showed potential. It was considered however, that further investigation would be beneficial to reduce singeing and degradation of the fabric surface. In addition to this, the results suggested that investigations into the affect of different fibre types and blends on the quality of laser cutting and marking achieved would also be beneficial. Further to this the affects of different fabric construction parameters on the quality of mark achieved would be useful.

6.7.1 Materials
The aim was to assess the impact of laser speed on reducing the amount of singeing resulting from laser cutting and marking on nonwovens made from a range of fibre types blended and containing a specific ratio of thermoplastic binder fibre. A selection of needled webs produced during Stage 2 was used in the work. The fabrics selected are indicated in Table 25 in Appendix 4.

For the laser marking investigations, the viscose and ramie webs that had been produced using different needling and thermal bonding parameters were used. The fabric construction details are documented in Table 26 and 27 in Appendix 4.
6.7.2 Sampling Method: Laser Cutting

The investigations were carried out using the laser cutting facilities within the Laser Optical Engineering Department at Loughborough University. The cutter used was a 'Diamond™ 64 Laser', made by the Coherent Laser Group, as shown in Figure 162. The laser is a modular RF exited, sealed industrial CO₂ 'pulsed laser'. The laser allows the user to control the power output by manipulating the 'Pulse Width' and 'Pulse Period'. The speed at which the laser cuts can also be controlled ('Coherent Diamond™ 64 Laser', User Manual, p.3). The laser runs in conjunction with the 'APS Ethos' CAD package.

The following cutting procedure was applied to each fabric; (1) the material was placed on the cutting bed and secured at its corners with tape and the safety doors were closed; (2) the focus height of laser head was set; (3) the design to be cut was loaded into APS Ethos and cutting speed set; (4) the laser was activated to cut the fabric and; (5) when the laser was back in its safety position the fabric was removed from the cutting bed.

Following the appropriate laser training, the researcher was able to operate the Laser herself, enabling a greater degree of involvement in, and reflection on the process. Owing to the
incremental nature of the training, however, only certain parameters could be controlled by the researcher at this stage of the work. Therefore, these investigations focused on the manipulation of laser speed. For clarity, each of the controllable parameters is outlined below.

6.7.2.1 Pulse Period and Pulse Width
At this stage in the research both the pulse period and pulse width settings remained constant at 30 and 70 respectively as recommended by the technician. Later in the research these settings were adjusted by the researcher to achieve the quality of cut required on certain fabrics.

6.7.2.2 Cutting Speed
The cutting speed was measured in mm/s. A list of recommended speeds at which to successfully cut a range of materials of various thicknesses was provided by the technician. Based on this list, speeds of 200mm/s, 300mm/s and 500mm/s were trialled on the fabrics. The speed was controlled through the Material Manager window in the APS Ethos package.

6.7.2.3 Focus Height
The laser head was focused by placing a small block of metal that had be cut to the correct dimensions on the fabric and adjusting the laser head so that it hovered just above the metal block.

6.7.2.4 Thermal Bonding
The samples were thermally bonded using the heat transfers press at a setting of 100°C for 10 seconds before cutting. At this stage, all samples were cut on the side that had been pressed.

The details of each sample cut are given in Table 25 in Appendix 4.

6.7.3 Observations and Reflections
6.7.3.1 Weight and Surface Quality
The observations confirmed those made during the initial investigations (section 6.3.3). As highlighted, the weight and surface quality of the fabric sample affected the quality of cut achieved. As illustrated in Figures 163 and 164, the lighter weight fabrics (LC2.13) resulted in smoother cleaner cuts than the thicker, heavier fabrics (LC2.9) on which singeing was more
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visible and the quality of cut was generally better on samples that were smoother and more compacted.

Figure 163: Sample LC2.13 (cutting speed 300)  
Figure 164: Sample LC2.9 (cutting speed 300)

6.7.3.2 Ratio of Binder Fibre

The results suggested that, broadly speaking, the greater the quantity of binder fibre the less the amount of visible singeing. However, singeing was also considerably less evident in those fabrics that contained synthetic rather than natural base fibres (LC2.1 and LC2.2). This is illustrated in Figures 165 and 166. The sample shown in Figure 165 has a greater quantity of binder fibre than that shown in Figure 166.

Figure 165: Sample LC2.1 (cutting speed 300)  
Figure 166: Sample LC2.2 (cutting speed 300)

6.7.3.3 Cutting Speed

All the samples were successfully cut at 200, 300 and 500 mm/s. The results demonstrate that there was little visible difference in the amount of singeing that occurred when cutting the samples at each speed. Figures 167–169 show three different fabrics each cut at 200, 300 and 500 mm/s.
Although all samples were successfully cut at the highest speed of 500 mm/s and the amount, of singeing reduced, it was still visibly evident. This meant that, as the process stood, to use laser cutting without spoiling the appearance of the fabric, the choice of nonwoven was limited to those with a high proportion of binder fibre or with a synthetic base fibre. In order to widen the possibilities and to improve the quality of cut on nonwovens with greater proportions of natural fibres, it was felt that further investigation of laser parameters would be beneficial. Owing to time constraints, however, further manipulation of laser parameters was integrated into Stage 4 of the practical research.

6.7.4 Sampling Method: Laser Marking

Further laser marking investigations were carried out using the facilities within the Laser Optical Engineering Department at Loughborough University. A ‘Synrad CO₂ laser marking system’ was used and is shown in Figure 175. The system has a maximum output power of 10 watts and a wavelength of 10.6. The system runs in conjunction with Synrad ‘Winmark’ CAD package and it is routinely used to mark a range of plastics, fabrics, leathers and wood at high speeds.
The procedure outlined here was followed to mark the fabrics; (1) the material placed onto the cutting bed and secured at its corners using tape; (2) the height of the cutting bed was altered to focus and the safety door closed; (3) design loaded into Synrad Winmark and the power, velocity and number of passes were set; (4) the laser was activated; (5) when cut the fabric was removed from the laser bed.

A number of the laser marking parameters could be adjusted to control the quality of mark. These included the power level, vector velocity and number of 'passes'. Following the appropriate laser training, the researcher was able to operate the laser marker herself, again, enabling a greater degree of involvement in, and reflection on the process. As with the Diamond cutter, training was incremental and at this stage covered only the basic parameters and functions of the equipment. The work therefore focused on manipulating to the power functions.
6.7.4.1 Power

The power was adjusted by specifying a percentage of the maximum 10 watt power output. Power levels of 30%, 50%, 80% and 100% were trialled on the fabrics in question. Details are given in Table 26 and 27 in Appendix 4.

6.7.4.2 Vector Velocity

It was noted that the higher the velocity the faster and lighter the mark. At this stage in the work the velocity was kept constant at 380 m/m.

6.7.4.3 Passes

The number of times the laser marks the fabric could be controlled by adjusting the number of 'passes'. At this stage in the work, unless otherwise noted, each fabric was marked with just one pass.

6.7.4.4 Focus

The laser head was focused for different materials by adjusting the height of the laser bed using a set measure as shown in Figure 175.

6.7.4.5 Thermal Bonding

Each of the needled webs bonded in the heat press on one side at 100°C for 10 seconds. The samples were marked on their pressed side. Further samples of each needled web were pressed on both sides.

6.7.4.6 Adapting the Process to Imitate Devoré

It was noted in the initial investigations that the laser marking process could be potentially used to achieve a similar surface effect to that of devoré. The initial investigations suggested that this was possible but the method used left the surface quality of some fabrics degraded and it was not possible to remove all burnt fibres by washing and rubbing. The marking process described previously was, therefore, adapted to create an etched effect with less or no singeing and to eliminate the need to wash off burnt fibres.

In the initial investigation, the entire surface of the motif was marked using a Bitmap file. In this investigation only the edge of the motif was marked using a Vector file. Following marking, the fibre layers within the marked edge were peeled away by hand. The mark essentially acted as a shallow cut enabling the top layer of fibres to be removed. The affect of
different fibre blends and fabric construction parameters on the success of this process were observed and noted in Tables 26 and 27 in Appendix 4.

6.7.5 Observations and Reflections
The sampling undertaken enabled the technique of marking and peeling layers of fibre to create an etched surface to be observed. The impact of different fabric construction and marking parameters on the results achieved were documented.

The technique was successful in that, the fabric within the marked areas was reduced in density creating a relief effect. The effect achieved, however, was a much 'harder' look than that achieved using the devoré process. All of the fibres within the peeled away areas were removed which created a more dramatic effect. The process revealed the middle layers of fibre and any embedded materials within the fabric. Figures 171 and 172 show examples of the results achieved. It was considered that this effect could be developed using fabrics with a range of fibre layers and embedded materials.

![Figure 171: Sample LM2.17.](image1)
![Figure 172: Sample LM2.5a.](image2)

6.7.5.1 Fabric Construction
The results suggested that the fabric construction parameters, alongside the laser power exerted on the sample, did affect the quality of 'etch' achieved using this technique. The depth of needling, extent of thermal bonding and quantity of binder fibre all had a subtle effect on the ease with which the marked areas were peeled away, the quality of etched surface and the extent of singeing.

Needling
It was noted that the greater extent of needling the more difficult it was to remove the area marked out by the laser owing to the greater level of fibre entanglement. Greater force was
therefore required to peel away fibre layers. This affected that quality of the surface remaining within the marked (or 'etched') area to a greater or lesser extent depending upon the type of fibre used. Heavily needled viscose fabrics resulted in etched areas in which needle marks (LM2.6c) or loops (LM2.5c) were evident. The more difficult it was to peel away the fibre layer the fluffier the etched area became. Similar effects were observed on heavily needled ramie fabrics, but rather than loops of fibre, tufts of fibre were evident (LM2.11c).

Figures 173-175 show examples of the heavily needled fabrics and Figures 176 and 177 show examples of the lightly needled fabrics.

**Thermal Bonding**

The extent to which the fabric had been thermally bonded before marking also affected the quality of the etch achieved. Fabrics that had been thermally bonded before marking resulting in 'harder', more defined marked edges as shown in Figures 173-177. The etched area was soft and fluffy in comparison with the smooth surface of the rest of the fabric. Fabrics that had not been thermally bonded before marking resulted in softer, and, less defined marked edges. The contrast between the main fabric surface and the area remaining within the peeled areas was comparatively small as shown in Figures 178 and 179.
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Quantity of Binder Fibre
As expected, the results suggested that the greater the quantity of binder fibre within the fabrics the less the amount of singeing that took place. It was also more difficult to peel away fibre layers within the marked areas of these fabrics (LM2.15a) as shown in Figure 180. Further to this the greater the quantity of binder fibre, the lesser the impact of the singeing on the fabrics. This resulted in a shallower mark and made it more difficult to peel away the layers (LM2.16a, LM2.14a) as illustrated in Figures 181 and 182.

Laser Power
The percentage of power used impacted considerably on the quality of mark achieved. As expected, the results suggested that the higher the power the greater the extent of singeing. In this investigation the viscose fabrics were singed to a greater extent than the ramie fabrics when marked at the same power level. Using a higher power, however, resulted in deeper
marks which made it easier to peel away fibre layers. Figures 183 and 184 show samples cut at the different cutting speeds applied.

In summary, varying the construction parameters before marking allowed the handle and general surface quality of the fabric to be controlled as well as determining the ease with which the marking and peeling process could be carried out. Further work using different fibre types, different fibre layers and embedded materials is described in Chapter 7.

6.8 Summary
This chapter described a series of investigations into the use of embossing, printing, laser cutting and laser marking as decorative finishing methods for nonwovens. The aim was to see if the fabrics produced in Stage 2 of the practical research, could be successfully embossed, printed, laser cut and marked and to observe the affect of different fibre types, fibre blends and fabric construction parameters on the effects achieved. The current use of these processes within the nonwovens industry was acknowledged but it was hoped that through taking a craft approach to these processes new surface effects might be achieved and the processes applied to wider range of fibre types and blends than currently used within industry. This chapter did not aim to provide scientific explanations for the observations and reflections made but to document the making process and the results achieved to enable future design development.

The chapter showed that embossing, printing, laser marking and cutting could be successfully applied to nonwovens made from a range of fibre types blended and containing a portion of thermoplastic binder fibre. The investigations confirmed that the fibre type, blend and fabric construction parameters do impact on the results achieved.
The results of the investigation into devoré printing were particularly significant. The process was adapted to better accommodate the properties of the nonwovens in question by drawing on paper making processes. This aspect of the work showed the potential for much design development and forms the basis of an original contribution to knowledge. However, due to the environmental implications of the devoré process, laser marking was explored as an alternative means of achieving a 'burn-out' effect. Two techniques were trialled and showed potential for design development that is as yet un-explored. Further work may include the use of enzymes to burn away fibres.
7.1 Introduction
This chapter discusses a number of periods of design development work that took place throughout the research. To reiterate, in Stage 1 a number of nonwoven design techniques were confirmed using hand-based methods. During Stage 2 these techniques were translated and adapted to pilot-scale machinery, in particular carding, needling and thermal bonding technologies. In Stage 3, the use of printing, embossing and laser cutting processes on the fabrics that had been produced were investigated. The work discussed in this chapter aimed to consolidate and further explore the design potential of the construction techniques and decorative finishing techniques established. This was achieved by developing a body of nonwoven designs suitable for high-end markets.

7.1.1 Aims and Approach
Each period of work aimed to develop upon specific design themes and construction techniques that had been established in the previous chapters. The approach taken was based around the researchers own methods of designing and incorporated the 'explicit rules of practice that are outlined in Chapter 3. The three stages of immersion, acquisition and realisation were applied to each period of work. Each of these stages is reviewed below.

7.1.1.1 Idea Generation
The 'immersion' stage involved selecting and preparing materials, preparing visual imagery, establishing the aims and desired outcomes of each piece of work and proposing methods of achieving those aims. This was documented in the researchers sketchbooks, examples of which can be seen in Appendix 5.

Visual Inspiration
Visual imagery was sourced and developed to provide design direction and inspiration. Following on from the visual imagery sourced during Stage1 (based around hedgerows and wildflowers) a natural theme based around florals was continued and as the work progressed other aspects were drawn in including lace imagery and simple striping. Other sources of reference included Japanese stencil work. Photographs, drawings and imagery were collated to inform materials selection, colour and pattern development and fabric planning.

7.1.1.2 Acquisition and Realisation
The ‘acquisition’ of information and data happened as the making took place and the ‘realisation’ stage was embedded in the reflections and observations made during and after
7.1.1.3 Analysis

The analysis was based on observations and reflections made before, during and after the periods of making. As outlined in Chapter 3, Victor Papanek’s ‘Function Model’ (1985, p7) was used as a framework for analysis. The synthesis of the analysis focused on the ‘Method’ aspect of the model which is described by Papanek (1985, p.8) as ‘the interaction of tools, materials and process in achieving the given the aims’. Within this, the potential to use the techniques and machinery to produce small runs of fabric was suggested. The possibility to produce the fabrics using full scale industrial equipment is discussed in Chapter 8. At this stage, the evaluation of the ‘Aesthetic’ aspect focused on a discussion of the visual and tactile qualities of the designs produced. A more in depth analysis of the aesthetic qualities of the fabrics was sought through the focus groups and interviews which will be discussed in Chapter 8.

The discussion in this Chapter is organised in terms of the design techniques and themes that were explored. These included:

- embedding fabrics and fibres between;
- embedding yarn;
- highlighting embedded elements;
- creating and revealing layers of texture;
- translucency and lamination;
- printing;
- embossing;
- colour.

Each of these techniques and themes are discussed within this chapter. The sampling processes used are outlined and the observation and reflections made are discussed. A visual summary of each technique or theme is included within the Chapter. A selection of the fabrics is documented in Fabric Documentation Sheets in Appendix 6.

7.1.2 Materials, Equipment and Working Context

The selection of materials used was based on those that had been used in the previous investigations. However, new fibres and materials were introduced to fully interpret the visual research and to expand upon the techniques that had been developed. Flax, linen and
various wool blends were added to the range of fibres used. The fibres and materials used in each fabric are documented in Appendix 6.

The periods of fabric construction work were short and intense lasting between one and three days. This was dependent upon the amount of sampling required and the time available. The first three periods of fabric construction work were carried out at the Centre for Materials Research and Innovation at Bolton University (CMRI) with the assistance of their technician. The final period of work was carried out at Loughborough University using Texon's pilot scale equipment. The equipment used was as that described previously in Chapter 4 unless otherwise stated.

All decorative finishing and fabric manipulation was undertaken in various departments within Loughborough University. The equipment used was as that described in Chapter 6 unless otherwise stated.

7.2 Embedding Additional Fibres and Fabrics

During Stages 1 and 2, new techniques of embedding additional fibres, yarns and fabric pieces into fibre webs at the carding stage of production were established using both hand-based and pilot scale nonwovens equipment. The techniques involved placing additional materials between individual fibre layers as they moved from the card to the layering mechanism. These techniques provided the opportunity to incorporate additional textural and surface qualities, compositional elements, fabric shapes, and additional colour into a basic web. In order to explore the aesthetic possibilities of these techniques, the following approaches were considered:

- Embedding unusual, luxury or 'extreme' materials
- Exploiting the translucent qualities of light-weight webs as a means of revealing embedding elements

7.2.1 Sampling Method

The fabric construction parameters used were based around the results of the previous investigations and are documented in Appendix 6. The fabrics were constructed as described below.

7.2.1.1 Fibre Preparation

The majority of the fabrics were made from a blend of 70% main fibre and 30% binder fibre. From the results of the research conducted in Stages 2 and 3, this was identified as a suitable blend to achieve good results in the printing, embossing and laser processes. The quality of
the fabrics made from this blend (in conjunction with the construction parameters outlined below) had a generally pleasing quality. At this stage in the work, the fibre quantities were calculated on the desired weight and size of web. The correct ratio's of fibre were weighed and carded once as a means of blending the fibres.

7.2.1.2 Web Formation
The fibres were processed in the card to produce a continuous fibre layer. As the fibres moved from the card to the layering mechanism, the additional materials were added by hand. The materials selected for embedding had distinct visual and tactile qualities such as corded paper yarns, metallic threads and fibres, gummed silk filaments, dried plant materials and laser cut fabric pieces. It was considered that such materials would be associated with niche or high-end textile products rather than low-end or mass produced textiles.

Due to the complexity of adding yarns to the webs, this aspect of the work is dealt with separately in section 7.3.

7.2.1.3 Web Bonding
The samples were lightly needled prior to thermal bonding in order to give them greater structural integrity. The extent of needling employed was based upon the weight of the web and the level of integration of embedded material required. Broadly speaking, however, needling was kept to a minimum and used as a means of tacking the webs prior to thermal bonding. The needling parameters used for each sample are noted in Appendix 6.

Thermal bonding was carried out using the heat transfer press described in Stage 1. The temperatures and dwell times employed were adapted for each fabric dependent upon intended further processing. Bonding details are also noted in Appendix 6.

7.2.2 Observations and Reflections
The technique of embedding additional materials was a central aspect of the work conducted. A range of materials were successfully embedded affording a number of different fabric 'looks'. Two design themes are discussed in relation to this technique: embedding unusual and luxury materials, and, exploiting the translucent qualities of lightweight webs. In relation to both these themes various points of analysis are made under the headings of 'Method' and 'Aesthetic'.
7.2.2.1 Embedding Unusual, Luxury and 'Extreme' Materials

A range of materials were successfully embedded affording a number of different fabric 'looks'.

Method

Due to the delicate nature of some of the materials and the heavy, unruly qualities of others, successful embedding required careful monitoring of the layering process. This often meant stopping and starting the machinery and relied on continual communication between the designer and the technician.

Stopping and Starting Machinery - Composition

Leaving the card continually running meant that the additional materials had to be scattered rather than placed in the web. This resulted in designs that were limited to effectively random compositions as shown in Figure 185. To enable more specific placement of materials the card was continually stopped and started. This did allow some control in regard to placement but it was not precise or repeatable but allows a 'one-off' fabric to be produced. This is illustrated in the fabric shown in Figure 186 which contains dried flowers positioned to sit in a band across the bottom of the fabric.

Figure 185: Sample DD1 showing the random placement of laser cut fabric motifs achieved by scattering between fibre layers.

Figure 186: Sample DD2 showing more controlled placement of floral elements achieved by stopping the card and cross-lapping line during production.
Although stopping and starting machinery during production enabled greater possibilities in terms of composition, it did cause some production problems. In some cases the process caused the webs to break and distort which affected the quality of the resulting fabric.

**Web Layering**

In terms of the layering process, as highlighted in Chapter 5, the weight and nature of the embedded materials affected the success of the layering process. Using large amounts of heavy or springy materials, such as cored yarn, tended to pull and distort the web during the layering process. This meant that the layering process had to be carefully monitored and often stopped and started to allow manual intervention to recover and restore elements of the web. This was time consuming and again required continual communication with the technician. The weight of the materials also impacted upon this stage of production. Small, heavy materials had a tendency to sink or fall to the bottom of the web during the layering process.

**Needling and Thermal Bonding**

The nature of the embedded materials affected the results of the bonding processes. Materials such as sequins were too dense and hard for needling. Such materials tended to remain on the needle after being ‘hit’ once. This stopped the needles from working properly and removed a large proportion of the embedded material from the final fabric and degraded its final quality. Once lightly needled, most of the fabrics were successfully bonded in the heat-press.

**Small Scale Production**

In regard to producing these fabrics on a small-scale or batch production level, the problems relating to stopping and starting machinery, monitoring the layering process and accessing the web to include additional materials would need to be addressed to enable efficient production.

**Aesthetic**

The embedding process was used to create both subtle and obvious designs. Complimentary and contrasting base fibres and fabrics were used to create different tactile impressions and colour combinations. Different fabric motifs, fibre types and threads were used to compliment printed and cut designs that were later applied. Perhaps the most interesting effect achieved was the sense of visual depth created by the inclusion of materials at various levels within the fabric. Although the embedded elements were covered by fibre layers, they gave the
impression of different tactile elements within the fabrics and affected the surface quality and handle of the fabrics. The 'visual summary' at the end of this section shows some of the fabrics achieved using this technique and key fabrics swatches are included in Appendix 6.

### 7.2.2.2 Exploiting the Translucent Qualities of Light-weight Nonwovens

By using particular combinations of base fibres and embedded materials it became apparent that certain materials could be almost hidden within the webs. The embedded materials only became visually apparent when the fabrics were viewed in front of a light source. Interesting effects were also achieved by embedding relatively heavy or dense materials in light weight webs. The materials appear almost suspended in the fabrics.

### Method

**Fabric Weight and Material Selection**

The main considerations in producing designs in which materials were 'hidden' within webs, were not only to ensure the right selection of materials, and to achieve a fabric with enough weight and density to conceal the embedded elements, but also to ensure that was translucent enough to allow light to penetrate. A successful example is illustrated in Figure 187 in which strips of Hessian fabric are embedded within a flax based web.

*Figure 187: Sample DD3 showing hessian ribbons in a flax web.*
Web Formation, Layering and Web Bonding

In regard to constructing fabrics with 'hidden' and suspended elements, issues relating to stopping and starting machinery and monitoring the layering processes (as described above) needed to be considered. In regard to 'suspending' materials in light weight webs, if the web was too light and the material too heavy the structural integrity was compromised. As a result of this the fabric was torn and distorted when needled. Some successful fabrics were, however, achieved. An example is shown in Figure 188.

Figure 188: Sample DD4
Fabric showing relatively heavy cut paper yarn in a light weight web creating a 'suspended' effect.

Small- Scale Production

In regard to producing these fabrics on a pilot scale production level, the requirement to stop and start machinery, monitor the layering process and access the webs to include additional materials would need to be addressed to enable efficient production. In addition the needling process would have to be carefully monitored when producing light weight fabrics with relatively heavy embedded materials to ensure a good quality fabric.

Aesthetic

These techniques enabled interesting visual effects to be achieved in regard to the fabrics interaction with light and the creation of a 'suspended effect'. The fabrics in which a 'suspended effect' was created also had an interesting handle due to the disparity in weight between web and embedded material. Each of these aspects could be developed further through the exploration of other material (and colour) combinations. The visual summary that
follows shows some of the fabrics achieved and key fabric swatches are included in Appendix 6.
Figure 189: Examples of nonwoven fabrics with fibres, filaments, yarn and fabric motifs embedded between fibre layers (samples from left to right DD5, DD6, DD7, DD8, DD2, DD9, DD10, DD11, DD12).
7.3 Embedding Yarn

Embedding lengths of yarn was identified in Stages 1 and 2 as a means of adding visual structure, texture and colour to carded webs. A number of techniques to do this were explored. As described in Chapter 2, it was possible to insert the yarn between the lap drum and the condensing roller using the Texon equipment. The yarn was taken up directly off the cone as the layers were built up. Using equipment CMRI, yarns were embedded by stopping and starting the production process and adding cut lengths of yarn to individual fibre layers as they travelled from the card to the layering mechanism. Although both techniques were, to some extent, successful it was considered that both processes had limitations and could be developed further. Although the technique used at Texon was consistently successful, it was felt that a wider range of yarns could be explored. In addition, it was not possible to produce lengths of fabric using the Texon system. It was felt, therefore, that developing a more consistent method of embedding yarns using the CMRI system would be beneficial as it reflected industrial production more closely. To do this the following approaches were considered:

- feeding yarn from a series of cones to the feed belt between card and lapping system;
- feeding pre-made warps to the feed belt between card and lapping system and;
- embedding a range of yarn qualities using the above methods.

From an aesthetic perspective, the aim was to create visual structure as opposed to the more 'random effects' created by embedding fibres, threads and fabric motifs.

7.3.1 Sampling Method

7.3.1.1 Feeding Yarn from a Series of Cones

The sampling was carried out using the CMRI card and cross-lapping system as described in Chapter 5. The following procedure was used; (1) between two and four cones of yarn were placed on a cone stand in front of the carding unit; (2) once a full belt (between card and lapping system) of fibre had been carded the production was stopped and each yarn was fed over the top of the unit, threaded into the web and held in position; (3) production was re-started; (4) as the belt moved the yarn was taken up from the cones and was taken into the lapper and the yarns became embedded within the layers of fibre; (6) production was stopped just before all of the fibre had been carded and; (7) the yarns were cut. This allowed a covering of web over the final layers of yarn to hold them in place.
7.3.1.2 Feeding a Pre-Made Warp between Web Layers

To enable a greater quantity of yarns to be embedded within the fabrics, the possibility of embedding pre-made warps into fibre layers was explored. The following procedure was used; (1) before web construction a series of warps were made, spaced across the width of a horizontal warp winder and wound on; (2) each end of yarn was attached to a flat stick; (3) the warp winder was positioned in front of the carding unit; (4) once a full belt of fibre had been carded the production was stopped and each stick was taken over the top of the unit, the yarns placed onto the web and held in position; (5) production was re-started; (6) as the belt moved the yarn was taken up from the warp winder and was taken into the lapper and the yarns became embedded within the layers of fibre; (7) production was stopped just before all of the fibre had been carded and; (8) the yarns were cut.

This method was also used in conjunction with the Texon equipment. The same procedure was followed except that the warp winder was positioned in front of the lap drum, rather than in front of the carding unit. The warp was fed between the lap drum and the condensing roller.

A range of standard and fancy yarns were selected to incorporate different visual and tactile qualities. These included various counts of silk and cotton, ribbon, paper yarn, boucle yarn, looped mohair, lurex and chenille yarns.

7.3.2 Observations and Analysis

The techniques were successful in creating visual structure within a number of fabrics. Some aspects of the processes used were, however, problematic causing inconsistent results. Both techniques of feeding yarns into webs are discussed below under the headings of ‘Method’ and ‘Aesthetic’.

7.3.2.1 Feeding Yarn from a Series of Cones

**Method**

Yarns were successfully embedded from a series of cones using the CMRI and Texon systems. To control the process, however, both systems required a high degree of hand intervention.

**Hand Intervention**

When using the CMRI system two people were required to hold the yarns in place as they were fed onto the web. It was necessary to guide the yarns by hand as they ran over the carding unit to prevent them from tangling. The whole process required constant
communication with technicians. When using the Texon system the yarns were less prone to tangling because of the shorter distance between the cones and the web.

**Quantity and Weight of Yarn**

When using the CMRI system problems were caused at the layering stage by feeding too much yarn, or too heavy a weight of yarn into the webs. If the quantity of yarns in any given section of the web was too great, the fibre layers did not encase the yarns, leaving them exposed and liable to be caught up in components of the layering mechanism. This disrupted and in some instances brought production to a halt, which had a detrimental effect on the quality of the final fabric. Similarly if the weight of the yarn was too great it pulled and distorted the webs, which also disrupted the layering system. It was possible, however, to control the stopping and starting process to cut and reinsert the yarns which minimised disruption to the webs.

The Texon layering system meant that the yarns were supported by the lap drum as soon as they entered the web. This meant that the webs did not have to support the weight of the yarns as they were layered. Therefore the webs were not disrupted by greater quantities of yarn.

**Yarn Type**

The type and nature of the yarn impacted upon how successful the embedding process was, particularly when using the CMRI system. Yarns that did not sit flat when not under tension, for example paper yarn, caused some problems. Once the yarns had been fed into the web and tension was realised the yarns sprang back, often breaking through the above layer of fibre. This created an uneven coverage of fibre and disrupted the layering process which resulted in an inconsistent web for needling. It was possible, however, to re-arrange and restore sections of the final web as it travelled toward the needle loom to produce a good quality fabric as shown in Figure 190. When less yarns were used, as shown in Figure 191, this was not a problem, as they could be more easily guided and controlled by hand.

A wider range of yarns were successfully incorporated when using the Texon system owing to the shorter distance between the cone and web. Further to this, the researcher could stand in closer proximity to the web enabling greater hand intervention and control. This is illustrated in Figure 192 which shows a sample incorporating silk and chenille yarns and Figure 193 which incorporates a fancy yarn.
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Figure 190: Sample DD14
Paper yarn in a ramie web.

Figure 191: Sample DD13
Linen yarn in flax web.

Figure 192: Sample DD15
Silk and Chenille yarns in ramie web.

Figure 193: Sample DD16
Bouclé yarn in wool web.

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The problems started by feeding the woven cloth into the weft were similar to those encountered when working with being raw denim and involved essential firsts in converting them directly from woven piece into the fabric. This method was used to handle the yarns involved over the next and industrial
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Small Scale Production

Using the CMRI pilot scale system, this technique could be used to produce lengths of fabric in small production runs but would rely on hand intervention. A device could, however, be employed to separate yarns as they travelled to the web to stop them tangling. Due to the way in which the cross lapper worked, the yarn would always run across the width of the fabric rather than along its length.

Aesthetic

In terms of aesthetics, this technique was to create fabrics with a greater sense of structure alongside a sense of visual depth. The samples produced did have a greater sense of structure than those fabrics that contained yarns that had been cut to a given length and added by hand. The yarns added using this technique still had a sense of movement, however, as they could not be fully tensioned or controlled to produce straight lines. The resulting fabric structures and compositions still had a sense of randomness.

The sense of visual depth created was dependent upon the ratio of yarn to web. Too much yarn meant that the sense of depth was not achieved as the yarns were too visually dominant within the fabric. Conversely, too many fibre layers masked the yarns completely.

The effect created by the yarns was predominantly visual but they did, however, impact upon the tactile and surface qualities of the fabric. Yarns on the surface of the fabrics created contrasting texture and often a relief surface quality. Larger quantities of yarn, or thick stiff yarns affected the handle of the resulting fabrics, often giving them a greater sense of pliability.

7.3.2.2 Feeding a pre-made warp into webs

Method

To successfully embed pre-made warps within webs the appropriate quantity and weight of warp for the weight and size of web being produced had to be selected. In addition selecting an appropriate type of yarn to enable suitable yarn tension and control to be achieved during the process was important.

Quantity and Weight of Yarn

The problems caused by feeding too much yarn into the webs were similar to those encountered when working with yarns from cones and revolved around the need to control yarn tension, prevent yarns from tangling and to minimise disruption in the layering process. Yarn tension was again controlled by hand as the yarns travelled over the card and into the
It was possible to separate yarns by hand when working with between ten and twenty yarn ends, but it became almost impossible when working with a solid warp due to the larger number of warp ends and the speed of the machinery. This was particularly difficult when using unruly yarns. In these instances the yarn was to some extent left to its own devices which resulted in spontaneous compositions.

The layering process was again, carefully monitored and adjusted by stopping and starting machinery. The increased number of yarns involved when using a warp made this more difficult to adjust and reposition the yarn owing to the greater weight and amount. This resulted in an uneven covering of web and an inconsistent quality of fabric as shown in Figure 194. Although the effect achieved was not planned the fabrics produced had a distinct quality that when combined with printing produced some interesting fabrics.

Yarn Type

As noted previously, unruly yarns were particularly problematic. A number of warps were, however, successfully embedded using this technique. Warps made up of fine wool, lurex, linen and ribbon yarns were used successfully as shown in Figures 194-197 and in the 'visual summary' in section 7.3.3. Once the process had begun these yarns ran relatively smoothly through the process.

![Figure 194: Sample DD17 Flax web with paper yarn warp.](image1)

![Figure 195: Sample DD18 Ramie web with lurex warp.](image2)
Small Scale Production

As noted above, this technique could be used to produce short runs of fabric but again, would be reliant on hand intervention. To reduce the inconsistency of the process, employing a device with which to separate yarns would be beneficial. Again, the yarn would always run across the width of the fabric rather than along its length.

It may be more successful to employ a large creel stand as used in industrial warp winding rather than employing a pre made warp. This would combine the two techniques of embedding yarn that have been explored here.

Aesthetic

Again the aim of employing these techniques was to achieve a sense of visual structure, visual depth and added textural qualities within carded nonwoven webs. When warps were successfully embedded, a sense of structure in the resulting fabrics was created. Owing to the nature of the process, however, the structure was not as controlled as was hoped. There was still a sense of randomness and spontaneity with the designs. This, however, was developed as a unique quality of the fabric designs.
Composition

The warps were designed before fabric construction to achieve a particular composition within the final fabric. It became apparent that when designing the warp it was important to take into consideration the speed of the conveyor belt that carried the web from the cross lapping system to the needle loom. As discussed in Chapter 5, the speed of this belt and the output belt to the needle loom controlled how closely together layers were placed on top of each other which impacted upon the composition of the warp in the web. If the belt remained still whilst the layer process took place, each layer of warp in web was laid directly on top of the previous layer. If the belt was placed in motion, each layer was placed on top of the previous but a certain degree to the left. This did not have a great impact on the final design when a solid warp of the same yarn was used, as shown in Figure 197. When the warp was more specifically designed, however, the belt was kept still so that the design appeared in the fabric as in the original warp as shown in Figure 196.

Visual Depth

As previously noted embedding yarns in this way created a predominantly visual impact but also affected the weight and structure of the fabrics and therefore their handle and surface qualities. In regard to visual depth, this was again dependent upon the ratio of yarn to web.
Figure 198: Examples of nonwoven fabrics showing embedded yarns between layers of fibre web. Samples (from left to right) DD19, DD18, DD20, DD21, DD22, DD17, DD15, DD23, DD24
7.4 Highlighting Embedded Fibres, Fabrics and Yarns

To push the design potential of fabrics containing embedded elements further, etching techniques were employed following fabric construction. The aim was to highlight and reveal the embedded elements within particular areas of the fabric design. The following techniques are discussed below:

- using devoré to highlight fibres and fabrics; and
- using laser marking to highlight fibres and fabrics.

7.4.1 Sampling Method

7.4.1.1 Devoré to Highlight Fibres, Fabrics and Yarns

All of the samples constructed for this purpose contained a percentage of cellulose fibre – either within the entire web or within discrete layers of the web. The webs were lightly needled and thermally bonded using the heat transfer press. Simple floral and striped surface designs, to compliment the arrangements of embedded elements with the webs were developed and exposed onto screens. The devoré process described in Chapter 6 (section 6.5.2) was employed. A number of the fibres used at this stage were dyed prior to construction using the methods outlined in Appendix 2. The processing details of the samples are included in Appendix 6.

7.4.1.2 Laser Marking to Highlight Fibres, Fabrics and Yarns

Following construction, the webs were lightly needled and thermally bonded in the heat-transfer press. Simple floral and striped Vector designs were developed using Adobe Photoshop and Adobe Illustrator for use in the marking process. The laser marking process, described in Chapter 6 (section 6.7.4), was applied to the fabrics. Initial trials were conducted on the samples of the fabrics. The marking parameters used were based on the results of the research conducted during Stage 3 of the research. Larger pieces of a number of designs were cut industrially using the trial settings as a guide.

7.4.2 Observations and Reflections

7.4.2.1 Devoré to Highlight Fibres and Fabric

In most of the samples produced, the embedded elements were already visible and the devoré process served to highlight them.
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Method

Depth of Embedded Elements

Devoré was successfully applied to the majority of the fabrics but a number of factors impacted on the effects achieved. The extent to which elements were revealed relied on the depth at which they were embedded and the depth of ‘etch’ achieved. If the additional elements were embedded too far beneath the surface, the devoré did not penetrate deep enough to reveal them. Further to this, the greater the number of layers there was to burn out the more binder fibre there was in the etched areas. This obscured the embedded elements from view.

Fibre Type and Blend

The type of fibre and blend used also impacted upon the effectiveness of this technique. As one would expect, those with a greater quantity of cellulose resulted in clearer and deeper etched marks, thus revealing the embedded elements to a greater extent as shown in Figures 199 and 200.

Figure 199: Sample DD25
Viscose fabric with clear lurex filaments, devoré printed.

Figure 200: Sample DD11
Viscose fabric with lurex filaments, devoré printed.

Dyeing fibres before fabric construction also impacted upon the effects achieved. If the binder and main fibre had not been effectively colour matched, the difference was highlighted
through the devoré process as shown in Figures 201 and 202. Although not desirable within some designs this effect could be used as a design technique.

**Small Scale Production**

Issues relating to the possibilities to produce these designs on a small scale production level are as those discussed in sections 7.2 and 7.3. The devoré technique used, as it stands, relies on hand production to enable careful finishing.

**Aesthetic**

The technique did highlight the embedded elements within the fabrics albeit to different extents. Visual and tactile contrast was achieved as well as the introduction of a relief surface effect and pattern. As in any fabric design, the type of materials, colour and surface patterns employed interacted to produce the final look of the fabric.

As noted previously leaving binder fibres un-dyed whilst using coloured base fibres, resulted in a strong colour contrast often detracting from the embedded elements of the fabric. Colour matching by dyeing the binder fibre resulted in less colour contrast allowing the focus to remain on the desired effect.

The type and composition of embedded material within the fabric and the pattern etched onto its surface interacted to create the look achieved. Devoré could be used either to emphasize...
or contrast the composition of the embedded elements as illustrated in the Visual Summary in section 7.4.3.

7.4.2.2 Laser Marking to Highlight Embedded Fabrics, Fibres and Yarns
The embedded elements were also highlighted using the laser marking technique that had been in Stage 3. Within this stage of the research, the process was used in combination with a wider range of fibre types and materials. The observations made during the making process are discussed below.

Method
Inconsistent fabric qualities
Although the fabric construction and laser marking parameters were based on the results of the investigations conducted in Stage 2, the process of marking and peeling away designs was often slow and inconsistent. This was partly due to the fact that the embedded elements created inconsistent fabric bonding and partly due to the fact that the peeling process was hand reliant. However, a number of interesting results were achieved as shown in Figures 203 and 204.

Figure 203: Sample DD27
Ramie fabric with goats hair, laser marked.

Figure 204: Sample DD28
Viscose fabric with black threads, laser marked.
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**Scale**
Due to the scale of the Synrad marking system it was only possible to mark in a 15cm² area. This made it difficult to produce larger samples. Example swatches were therefore passed on to a commercial laser cutter to mark larger samples. The level of depth of mark was not, however, as deep and as such the fabrics were not as successful as the swatches that had been marked using the Synrad system.

**Small Scale Production**
In regard to the base fabrics, the potential to produce these fabrics on a small-scale production level relates to the issues outlined in section 7.2 and 7.3. In regard to the laser marking process, due to its time consuming nature it would likely be appropriate for 'one-off' production only and suitable for the niche or commission market.

**Aesthetic**
The laser marking process resulted in 'etched' areas with hard, clean edges as opposed to the soft gradual edges resulting from the devoré process. Thus patterns and fabric surfaces achieved often had a harder graphical quality and the sense that the top layers of web were sitting on top of the main body of the fabric rather than integrated with it. This was due also to the fact that, in the area marked, the entire top layer was peeled away rather than only a portion of it as in the devoré process. The results, however, did show potential for development.
7.4.3 Visual Summary

Figure 205: Examples of nonwoven fabrics showing embedded fabrics, yarns and filaments which have been highlighted using devoré and laser processes. Samples (from left to right) DD21(3), DD28(2), DD3(2), DD25, DD11(2) DD11 (2) 28
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7.5 Creating and Revealing Layers of Texture

Creating nonwovens with contrasting texture and tone was one of the design themes emerging from Stages 1 and 2 of the practical research. As discussed in Chapters 4 and 5, controlling the placement of fibre within the web, adapting fibre blends and creating webs with layers of different fibre, are all known as methods of creating contrasting tone and texture. However, the notion of revealing contrasting fibre layers through devoré and laser etching processes is a new concept. Applying the devoré and laser marking processes described previously to specially designed nonwovens to create contrasting tone and texture in conjunction with surface pattern formed the basis for this area of exploration.

The following stages of the process were explored and documented:

- fabric construction;
- devoré and;
- laser marking.

7.5.1 Sampling Method

7.5.1.1 Fabric Construction

Samples were produced using the CMRI and Texon equipment. In regard to the CMRI system two methods of construction webs with different fibre layers were employed. The first method required the output belt to remain still as the fabric layers were built up. This enabled the fibre webs to be laid directly on top of each other which allowed specific layer combinations to be achieved. The fibre for each layer was fed into the card in the order in which the different layers were required. This method meant, however, that the size of fabric that could be produced was limited in this production context. The second method involved constructing larger, individual light weight webs and combining them before consolidation. Each individual web was removed from the construction line and then fed carefully onto the output belt as the final layer was cross-lapped on top. The combined layers were drawn towards the needle loom for bonding. When using the Texon equipment different fibre layers were built up by controlling the order in which the fibres were fed into the card. The fibre for each layer was fed into the card in the order in which the different layers were required.

The top layers of the webs contained a portion of cellulose fibre to enable them to be devoréd. Fibres used included linen, flax, ramie, cotton and viscose. For those that would be etched using the laser marking system a variety of fibres were used. At this stage in the work only ecru fibres were used. A ratio of 30% binder fibre and 70% main fibre was used in the majority of the fabrics.
Each web was lightly needled and thermally bonded in the heat transfer press before devoré printing and laser marking. The processing details for each fabric are included in Appendix 6.

7.5.1.2 Devoré and Laser Marking
The devoré and laser etching processes were carried out as described in Chapter 6 in sections 6.5.2 and 6.7.4 respectively.

7.5.2 Observations and Reflections

7.5.2.1 Construction Process

Method
Both methods of creating webs with different fibre layers using the CMRI system were effective. The possible fibre combinations were limited only by which fibres it was possible to card.

Small scale production
The main limitation of this construction process was scale. When using the first method the size of the fabric was limited to the area directly beneath the layering system. Using the second process enabled longer lengths of fabric to be constructed but was reliant on careful hand intervention meaning that the process would be potentially slow and therefore expensive.

7.5.2.2 Devoré Process

Method
The devoré process was successfully carried out on the majority of the fabrics constructed. It did enable different fibre types to be highlighted and created contrasting surface texture and relief pattern. Similarly to when using this process to highlight embedded materials, however, as noted in sections 7.2 and 7.3, the extent to which this was achieved was dependent on getting the correct number of cellulose based fibre layers on the surface of the fabric. If the top layers of the fabric were too dense then the devoré did not penetrate deep enough into the fabric to reveal the middle layers of the structure. Further to this, the quantity of binder fibre between the surface and the middle layers was greater which meant that the middle fibre was obscured by the binder fibre to a greater extent resulting in a reduction in the level of contrast as shown in Figure 206. The optimum number of top layers effectively covered the middle fibres but was thin enough to enable the devoré process to etch through the top layers as illustrated in Figures 207 -209.
Small scale production

The possibilities of using this technique in a small scale production relate to the issues raised in sections 7.4. Further to this, the limitation in regard to the size of fabric that could be produced would need to be considered. As noted above, producing lengths of fabric using pilot scale production equipment would rely on hand intervention. In regard to larger scale
production nonwoven lines exist which have numerous cards which enable a variety of fibre layers to be combined in continual production.

**Aesthetic**

Certain combinations of fibres resulted in greater levels of contrast than others from both visual and tactile perspectives. Colour, tone and fibre quality impacted upon this. For example the smooth, shiny consistent nature of ramie fibres contrasted strongly against the mottled broken colour of the lighter wool fibres. Combining less contrasting fibres in terms of colour and texture created more subtle surface effects. The areas of fabric that had been devoréd became less dense. These areas were more transparent and when held to the light created an impacting visual effect. The greater the contrast in terms of colour and density between the top and middle layers the clearer the pattern. These effects are illustrated in the Visual Summary in section 7.5.3.

**7.5.2.3 Laser etching**

**Method**

**Consistency**

The laser marking process proved a successful means of removing the top layers of fabric constructed with different fibre layers. As noted in section 7.4.2.2 there were some problems in regard to this process relating to consistency. Because the fabrics did not include additional materials, however, this was less of a problem when working with these fabrics.

**Scale**

Again, the size of the Synrad's marking area meant that the size of design was limited. Larger fabrics pieces were, however, produced by marking one repeat area at a time and lining the fabric up for further repeats.

**Small Scale Production**

Although, laser marking technology is used widely in textile manufacturing, the process, as described here could not be fully implemented for production owing to the reliance on hand work to remove cut layers of fibre. As noted in section 7.4.2.2, because of this, the process as it stands would only be feasible for 'one-off' or commission production.
Aesthetic

As described in section 7.4.2.2, the laser marking process produced fabrics with quite different visual and surface qualities to those produced using the devoré process discussed above. The resulting patterns and fabric surfaces often had a harder graphical quality as illustrated in Figure 210. As illustrated in Figure 211, when very textured fibres were used, however, the edges were a little less sharp producing slightly softer results. As discussed in 7.5.2.2, the combination of fibres in terms of texture, colour and tone interacted to create the look achieved. This is shown in the visual summary in section 7.5.3.

Figure 210: Sample DD34 Ramie web (two tone), laser etched.
Figure 211: Sample DD33 Wool (two tone), laser etched.
Figure 212: Nonwovens made from contrasting fibre layers, revealed through devoré and laser etching. Samples (from left to right) DD32, DD31, DD30, DD36, DD32, DD34, DD33, DD35.
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7.6 Printing

During this stage of the research the use of traditional screen-printing techniques was further explored. The aim was to explore the potential of printing on nonwovens of different weights, fibre blends and with embedded elements to create unique designs.

7.6.1 Sampling Method

The printing methods described in Chapter 6 were used. Due to the delicate nature of a number of the fabrics and the difficulty experienced in washing-off some of the samples in preliminary printing experiments, a gentler washing off process was employed in order to retain the surface quality of the samples. Rather than rinsing and rubbing the printed samples, they were placed in a resin bath and washed down using a low pressure hose. This allowed the fabrics to be kept flat and enabled any excess dye to be removed effectively without visible wearing of the fabric surface. Details of selected samples that were printed are given in Appendix 6.

7.6.2 Observations and Reflections

Method

Conventional printing processes were successfully employed on a range of fabric weights made from a range of fibre types including viscose, wool, flax and ramie. As outlined above, the main requirement for achieving successful results was to employ careful washing-off following printing and fixing.

Small Scale Production

The potential to produce the fabrics in a small-scale production context relates to the discussions outlined in the previous sections of this chapter. In regard to printing, due to the delicate nature of the fabrics they would need to be printed by hand to ensure that quality was retained.

Aesthetic

The quality of print achieved was dependent upon the weight and surface quality of fabrics and the type of materials embedded within them. In regard to fabric weight, as with conventional fabrics, denser fabrics could hold more dye than light weight fabrics and so resulted in more solid prints as illustrated in Figures 213, 216 and 217. An interesting effect was created by the different level of dye up take between the base fabric and the embedded elements. The effect achieved was dependent upon the type of material in the main fibre type within the fabric. For example, as shown in Figure 214 and 215, cotton yarn embedded in a

220
lightweight ramie web took-up more dye than the base fabric which resulted in a defined mark within the design.

Fabrics in which bulky or large amounts of materials had been embedded created uneven fabric surfaces which resulted in uneven and broken prints, as shown in Figure 216. Conversely, fabrics with a smooth surface resulted in solid clear prints as shown in Figure 217. Both types of print could be exploited for design purposes.
Figure 218: Printed nonwovens with embedded materials
Samples (left to right): DD48, DD17 (2), DD21 (2), DD21 (2), DD21 (2) DD38, DD40, DD40, DD39, DD39, DD40 (2)
7.7 Lightweight Fabrics, Translucency and Lamination

As alluded to previously, the ability to create nonwovens that ranged in weight and opacity became one of the focal points within the design work, in particular the potential to create lightweight translucent fabrics. Within this aspect of the work the following processes were explored as a means of exploiting the translucent qualities of the fabrics in relation to surface pattern:

- devoré and lamination and;
- laser cutting and lamination.

7.7.1 Sampling Method

7.7.1.1 Fabric Construction

Webs of between 15gsm² and 50gsm² were made using 70% main fibre and 30% binder fibre. The majority of the fabrics were lightly needled and thermally bonded at relatively low settings to allow the fabrics to be further bonded at the lamination stage. Construction details are given in the Fabric Documentation Sheets in Appendix 6.

7.7.1.2 Devoré

The fabrics were devoré printed using the equipment and technique outlined in Chapter 6 section 6.5.2. All samples were washed off in a resin bath and pressed in a paper maker’s press to aid drying. A number of simple floral and striped designs were exposed onto screens for use in the work. The processing details for each fabric are included in Appendix 6.

7.7.1.3 Laser Cutting

The fabrics were laser cut using the Coherent CO₂ Diamond Laser cut described in section Chapter 6. Different speeds, pulse widths and pulse periods were trialled on small samples before cutting the actual designs. The parameters used were based on the results of the work conducted in Stage 2. To reduce singeing, the fabrics were sprayed with a light water mist before cutting. A number of simple floral and striped vector designs were developed within Adobe Illustrator for cutting.

7.7.1.4 Lamination

Between two and three light weight laser cut and devoré printed samples were laminated using the heat-transfer press. The fabrics were layered together, placed between two sheets of release paper and pressed at between 150°C and 180°C. Pressing the samples at a
temperature higher than the original bonding temperature meant that the binder fibre was further liquefied, creating bonds between the fibre surfaces.

7.7.2 Observations and Reflections

7.7.2.1 Devoré and Lamination

Method
The majority of fabrics were successfully devoré printed and laminated. There were some problems, however, relating to the structural integrity of certain fabrics. Fibre blend and lamination settings also affected the results achieved.

Structural Integrity
As noted previously, achieving a good quality devoré effect on light weight nonwovens relied on using a delicate washing off process in order to retain the structural integrity and surface quality of the fabric. However, some of the webs were too weak for processing in this way, even when carefully handled. A number of the fabrics began to break down in the washing off process. This resulted in pattern with little definition.

Fibre Blend
Fabrics in which the main and base fibres had been blended uniformly resulted in a more consistent quality of pattern. Those fabrics that had not been as uniformly blended resulted in an inconsistent quality of pattern and surface.

Lamination
Once printed, washed and dried, the fabrics were laminated using the heat transfer press. As noted, the process was most successful at temperatures between 150°C - 180°C. At lower temperatures some fusing of surfaces occurred but the fabrics could be easily pulled apart. At temperatures above this range, however, the fabrics were more firmly fused but the handle became stiffer and more plasticized, as one would have expected.

Small Scale Production
In terms of producing these fabrics on a small scale production level, the main consideration would be the need for a careful washing and drying process which may rely on hand. The lamination process used shows potential for efficient production as no further processing equipment or bonding solutions, would be required.
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Aesthetic

Using devoré and lamination processes in conjunction with lightweight nonwovens produced fabrics with a soft, delicate visual quality. The translucent quality of the fabrics was emphasised within the patterned areas through the layering process, as illustrated in Figure 219, and some interesting effects were achieved through the interaction of multiple patterns and light. When fabrics with different coloured layers were viewed against an opaque background some interesting effects were achieved as illustrated in Figure 220. The type of colour and pattern and fibre type interacted to create the look of the fabrics.

![Figure 219: Sample DD41 Ramie webs, devoré printed and laminated.](image1)

![Figure 220: Sample DD42 Ramie webs, devoré printed and laminated.](image2)

7.7.2.2 Laser Cut and Lamination

**Method**

The cutting process was generally successful providing the correct settings for each fabric were established. Up to three layers of cut fabric were successfully bonded using the heat-press.

**Small Scale Production**

The cutting process could in theory be carried out on an industrial level to enable small production runs to be achieved.

Aesthetic'

The laser cut and laminated lightweight fabrics were similar in quality to the fabrics that had been devoré printed and laminated except that the type of mark or edge achieved within the patterns was much harder. Cutting the fabrics made clean holes rather than areas of reduced
fabric density. This resulted in a more 'graphic' look, as shown in Figure 221. If only one layer of cut fabric was used with a layer of uncut fabric, the cut layer formed the back rather than the face of the design, then the effect was softer as shown in Figure 222.

Cutting and laminating heavier fabrics created an almost relief effect as shown Figure 223. If the cutting parameters were carefully adjusted, it was possible to cut through the fabric but not the yarn that had been embedded within. The sample in Figure 224 illustrates the effect achieved.
7.7.3 Visual Summary

Figure 225: Devoré, laser cut and laminated nonwovens.
Samples (left to right): DD43, DD44, DD44, DD42, DD41, DD45, DD50, DD14, DD49, DD48(2)
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7.8 Embossing

The aim of this stage of the work was to create three dimensional patterns on nonwovens made from a range of fibre types and of different weights using studio based equipment.

7.8.1 Sampling Method

7.8.1.1 Fabric Construction
Carded webs were lightly needled and thermally bonded before embossing. The construction details are given in Appendix 6.

7.8.1.2 Embossing
The embossing technique documented in Chapter 6 section 6.3 was employed. The optimum embossing parameters established were employed. The fabrics were dampened before embossing using a light water spray. A number of designs were developed using Adobe illustrator and two lino and one steel plate were laser cut for use as embossing plates.

7.8.2 Observations and Reflections

Method
Embossing
During this stage of the research, the embossing process that had been established in Chapter 6 was not as successful as it had been during Stage 3 of the research (ref). This may have been due to the different types of plate and the designs used. The steel plate cut used for this stage of the research was 4mm rather than 2mm. This may have affected how successfully the plate conducted heat. Further to this, the design motifs employed were smaller and more intricate than those used in Stage 2 which may have affected the impact of the emboss achieved.

Although less successful than previous results, three dimensional pattern was achieved on a number of fabrics. Fabrics with smooth highly consolidated surfaces achieved a better defined emboss. Fabrics with less consolidated or more voluminous surfaces resulted in less clear forms.

Small Scale Production
As noted previously, calendaring is used within the nonwovens industry to emboss fabrics on mass production scale. The rollers used in the processes employed are costly to engrave. The embossing process established in this research is comparatively cheap to set-up
meaning that a wider range of designs could be produced and more frequently. This makes the process more suitable for small production runs than calendaring.

Aesthetic

The fabrics shown in the visual summary in section 7.8.3 show a range of the embossed fabrics. As well as gaining a relief surface pattern, generally speaking, the fabrics became smoother and stiffer through the embossing process owing to the additional heat and pressure applied to the fabrics. Embedded materials had an additional affect on the quality of emboss achieved.

7.8.3 Visual Summary

Figure 226: Embossed nonwovens.
Samples (left to right): DD46, DD50, DD47, DD8(2)
7.9 Colour

The use of colour was an integral part of the design development process. The aim in regard to colour was to explore various ‘types’ of colour including:

- neutral and naturals;
- brights;
- pastel, pale and soft colours and;
- deep or rich colour.

It was hoped that during the focus groups and interviews the impact of these different types of colour on the aesthetic quality of the fabrics would be assessed.

The methods used to dye fibres and fabrics are discussed in this section. The aim was not to assess the dying process in a scientific manner but to colour the fibres and fabrics to enable design development.

7.9.1 Sampling Method

Two methods of incorporating colour into the fabric other than printing and embedding coloured materials were used. The first was to dye fibres before fabric construction and the second was to dye the fabric following construction.

7.9.1.1 Dyeing Fibres Prior to Construction

Fibres were dyed before construction by hand using appropriate dye stuffs and conventional dye recipes and procedures. The M1440 polyester bi-component binder fibre was dyed using dyes stuffs and procedures recommended by the manufacturer. As noted previously details of the dyestuffs and recipes used can be found in Appendix 2. After dyeing the relevant fibre blends were created by carding prior to web construction.

7.9.1.2 Dyeing Fabrics Following Construction

Following construction the fabrics were dyed by hand using the appropriate dye stuffs and recipes.

7.9.2 Observations and Reflections

As illustrated in the ‘Visual Summary’ sections of this Chapter, neutral, tonal, pastel, bright and deep colour ranges were achieved. A number of factors impacted on the quality of colour achieved and the quality of the resulting samples including: the need to colour match for fibre
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blends; achieving the required depth of shade; issues relating to dying fabrics after construction.

**Colour Matching Base and Binder Fibres**
The need to colour match the base and binder fibre was a significant challenge when dyeing the fibres before fabric construction owing to the limited number of dyestuffs available (and appropriate) for the binder fibre. The range of colours achievable was limited and although it was possible to use each dye to achieve a different depth of shade, mixing the dye stuffs to create new colours was more difficult. This was due to the limited compatibility of the recommended dyestuffs.

A number of fabrics were produced using dyed base fibre and un-dyed binder fibre. This meant that the colour of the fibre blend was lightened. Dependent on the colour of the base fibre, the white binder fibre was prominent to a greater or lesser extent within the resulting web. This also impacted on the results achieved in the devoré process as noted in section 7.4.2.

**Depth of Shade**
The depth of shade achieved on the fibres appeared much lighter in the resulting fabric. As the fibres were opened the intensity of colour appeared to decrease. The appearance of colour in lighter weight fabrics, where the final fabric structure was more open, was less intense than the appearance of the same colour in relatively heavy fabrics in which the fibres were more densely packed.

**Dyeing Following Fabric Construction**
This process worked in that the fabrics were successfully coloured. The agitation and rinsing processes required, however, degraded the surface quality of the fabric. Further to this, because the fabrics were made of at least two fibre types cross dyeing was required. Due to the special procedure required to dye the binder fibre the colour options were again limited. Owing to the process required to dye the binder fibre the fabrics had to be in the dye bath for long periods of time which reduced the quality of the final fabrics.

**7.10 Chapter Summary**
This chapter has described several periods of design development work. The aim of the work was to develop a body of nonwoven fabric designs for high-end textile markets. The work was based around the fabric construction and finishing methods that had been established in
the previous Chapter 5 and 6. The chapter discussed the application of eight design techniques/themes. The Victor Papneks (1985, p7) function complex was used as an analytical framework. The analysis focused on aspects of ‘method’ (the interaction of materials, machinery and processes) and ‘aesthetic’ (focusing on the visual qualities of the resulting fabrics). Based on the researchers own experience of the processes in question, the possibilities and limitations in regard to producing the fabric designs on a small scale production level using pilot equipment were suggested. The analysis that was made is summarised below.

7.10.1 Embedding Fabrics, Fibres and Yarns between Layers of Web

The process of embedding fabrics, fibres and yarns between layers of web enabled colour, simple motifs and different textural elements to be integrated into the nonwoven structure. A sense of visual depth was achieved and the addition of yarns enabled an impression of structure to be achieved within the designs. The main limitations of this technique related to the compositional effects that were possible. A number of observations in regard to the incorporation of this technique into small scale production runs were made. It was noted that the technique relied heavily on hand intervention and the careful monitoring of production. Dependent of the type and quantity of the embedded material, production had to be stopped and started to enable the required quality of fabric to be achieved. This process relied on constant communication between the production technician and the researcher.

7.10.2 Highlighting and Revealing Embedded Elements

The devoré and laser marking techniques were employed in conjunction with surface patterns to enable the embedded elements within the fabrics to be highlighted or revealed. Contrasting visual and textural qualities were achieved and certain aspects of pattern were emphasised through this process. It was noted that the effectiveness of the devoré process relied on embedding the additional materials at an appropriate depth within the fabric and the use of an appropriate blend of cellulose, non-cellulose base fibres and binder fibre. The quality of fabric achieved was reliant on hand based finishing processes. This was noted as the main consideration in regard to small scale production.

7.10.3 Creating and Revealing Layers of Texture

The chapter outlined the production method used to produce nonwovens with discrete layers of different fibre types. The devoré and laser marking techniques enabled these fibres to be revealed creating textural and colour contrasts and relief pattern within the designs. To successfully achieve these effects it was noted that the correct fibre blend within each layer and the correct sequence of these layers within the fabric was required. In regard to small
scale production runs using pilot scale equipment it was noted that hand intervention was required to produce lengths of fabric. However, it was noted that in industry techniques exist that could overcome this problem.

7.10.4 Printing
Conventional screen printing techniques were successfully employed on nonwovens made from a range of fibre types and of varying weights. When fabrics with embedded elements were printed some interesting effects based around the different dye up take levels of the materials employed and the base fibres were achieved. Owing to the fragility of a number of the fabrics, a gentler washing process following printing and fixing was employed. This was noted as the main consideration in producing small runs of fabric.

7.10.5 Embossing
The embossing techniques established in Stage 3 of the research were applied to nonwovens made from a range of fibre types. Although hand reliant, the process showed potential as a more economical way of producing embossed pattern using heat and pressure than the calendaring processes used in industry. The ability to produce embossing plates relatively cheaply meant that the process was appropriate for use in small production runs where a greater number of patterns may be required.

7.10.6 Lightweight Fabrics, Translucency and Lamination
The ability to create lightweight, translucent fabrics using nonwoven production methods was exploited by devoré printing and laser cutting multiple webs and laminating them using heat and pressure. The fabrics produced were particularly effective when viewed in front of a light source. The surface patterns employed took on an ethereal and delicate look that was unlike that produced using conventional textile structures. In regard to small scale production, the base fabrics used could be efficiently produced. Owing to the delicate nature of the fabrics, the devoré printing processes would be best carried out by hand.

7.10.7 Colour
The use of colour in the work aimed to cover neutral, pastel, bright, tonal and deep colour ranges. This was successfully achieved by dying fibres prior to fabric construction and by piece dyeing fabrics following construction. The colour achievable was limited by the range of dyes available and the special process required to dye the binder fibre successfully.
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Focus Groups and Interviews

8.1 Introduction
Discussion around research that involves design practice recognises the complexity of design situations (Antilla, 1995, Broadbent, 2003 and Gray and Malins, 2004). The requirement to generate different perspectives on research problems and results is therefore acknowledged. As outlined in the Chapter 3, in academic research, the process of generating different perspectives on one problem is traditionally referred to as ‘triangulation’ (Gray and Malins, 2004, pg.31). Triangulation enables ideas to be inter-subjective, less biased and tested which enables critical results and conclusions to be obtained. Within the framework of naturalistic inquiry used in this research, triangulation supports and underpins notions of validity and trustworthiness. To test the ideas resulting from the researchers reflective analysis of the practice element of this research, and to develop inter-subjective results, a series of focus groups and interviews were conducted and analysed. The analysis in this Chapter focuses on the ‘aesthetic’, ‘method’ and ‘use’ aspects of Papanek’s (1985 p.7) Function Complex Model.

8.1.1 Aim and Approach
The aims of this aspect of the work were to;

- generate external evaluation on the aesthetic qualities of the fabrics developed;
- establish the suitability of the fabrics for various and specific end uses and markets and;
- develop ideas relating to the production potential of the fabrics within current commercial nonwoven manufacture;

To do this, a series of focus groups and semi-structured interviews were carried out with representatives from the textiles and product design area and the nonwovens manufacturing sector.

8.1.1.1 Focus Groups and Interviews
Focus groups can be described as ‘carefully planned discussions aimed to obtain the perceptions of the group members on a defined area of interest (Langford and McDonagh, 2003, p.2). Interviews, within design research, can be defined as a means to ‘elicit information that is known only to the users of the product or system in question’ (Jones, Design Methods, Chp 3.4). As discussed in Chapter 3, focus groups and interviews are used within design research for a number of purposes as highlighted by theorists Langford, McDonagh (2003 p.7) and Ireland (2003, p. 23-24). Within this research they have been used to:
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- engage with potential users to evaluate the fabric concepts from an aesthetic perspective;
- establish possible end uses for the fabric concepts and;
- gain an indication of manufacturing opportunities and limitations in relation to the fabric design produced within the research.

8.1.1.2 Work Undertaken

Two sets of focus groups and two sets of interviews were conducted. They were conducted at what were considered critical stages within the practical work, before and after major periods of development, to generate external review throughout the research. The sets of work can be described as follows:

- set 1: focus groups with textile and product design students;
- set 2: focus groups with textile academics and professionals
- set 3: interviews with interior product design professionals and;
- set 4: interviews with nonwoven manufacturers.

It has been noted that within design research, focus group members and interviewee's are usually selected based on their individual characteristics in relation to the subject of the session (Langford and McDonagh 2003 p.7). Theorists suggest that participants should be selected through 'purposive sampling' by selecting participants that belong to specific user groups (Morgan, 1997; Erlandson 1993 in Langford and McDonagh, 2003, p. 28) and are reasonably knowledgeable and interested in the subject at hand (Langford and McDonagh, 2003, p. 28).

The groups of participants outlined above were considered as having specialist knowledge in relation to textile design, product design and nonwoven manufacture, thus enabling critical evaluation of the fabric concepts to be generated. It was considered that each group of participants would be able to offer valuable insights relating to the aims of this stage of the research from design and manufacturing perspectives.

This Chapter covers the following areas in connection to each set of focus groups and interviews:

- focus group/ interview participants;
- discussion contents and structure;
- fabric selection;
- documentation methods and focus group tools;
- analytical techniques and;
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- results and discussion.

The first set of focus groups (with textile and product design students) acted as a pilot study and as such is included in Appendix 7 rather than the main body of the text.

8.2 Focus Groups with Textile Design and Design Professionals

Two focus groups were conducted during the design development stage of the research. The first group was conducted following the first two periods of making and the second following the third. The aim of these groups was to generate external evaluation on the aesthetic qualities of the fabrics developed and to establish the suitability of the fabrics for various and specific end uses and markets.

8.2.1 Participants

The participants selected for these groups were all professionals working as design practitioners and/or within design education. The first group included three printed textile designers, one woven textile designer and two design historian/theorists. All participants were also involved in design research and/or education. The second group included one printed textile designer, two woven textile designers and one ceramic designer. It was considered that these participants would again, be able to analyse the fabrics systematically and consider the fabrics within the broader context of current textile design practice and textile markets.

8.2.2 Focus Group Environment

The first group was conducted in a textile design studio and the second in a seminar room. Both environments afforded considerable natural light enabling the fabrics to be viewed against natural and synthetic light sources if wished. This was considered as an important consideration following comments made in regard to transparency and light during the pilot focus groups.

8.2.3 Discussion, Contents and Structure

The discussion contents remained located within the framework of Papanek’s function complex. Although the discussions covered each of the function aspects to some extent they were more directed to the ‘aesthetic’ and ‘use’ aspects as these were the areas of interest within the aims of this research. Further to this, it was considered that the participants’ expertise in design and their knowledge of current markets and products would be drawn out through discussion in these areas.
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The group was structured using what is described as a ‘funnel approach’. Morgan (1997, p.41) explains that the ‘funnel approach’ enables open or unprompted responses to be given in the initial stages of a focus group and allows the discussion to become more focused on issues that the researcher is interested in as the session progresses. A ‘moderator’s guide’, was used as a tool with which to direct the discussion in this way (Langford and McDonagh 2003, p.31).

The groups were structured in the following way:

1. fabric viewing and handling;
2. response form completion;
3. participants asked to discuss their initial responses to the fabrics and;
4. questions relating to response form topics:
   - prominent aesthetic qualities;
   - associations in terms of materials and products;
   - market value;
   - potential end use;
   - physical properties (subjective) in relation to end use;
   - most successful and most unsuccessful fabrics;

8.2.3.1 Fabric Selection
Thirty-four fabrics were selected by the researcher from those developed in the first two periods of design development work for use in the first group. The selection was intended to be representative of the fabrics produced. For the second group, two of the participants were asked to view the fabrics prior to the discussion and to select a range of fabrics that they considered were successful and a range that they considered unsuccessful for use in the discussion. This was done to reduce the number of fabrics viewed and to minimise any bias in the selection process. The fabrics that were selected are listed in Appendix 8.

8.2.4 Documentation and Focus Group Tools
8.2.4.1 Audio Taping
The focus groups were primarily documented using audio - taping. Morgan (1997, p. 54) writes that this is the principle means of capturing observations in focus groups.

8.2.4.2 Product (Sample) Handling
'Product Handling' is considered by Langford and McDonagh (2003, p. 24 and175) as a primary tool for design concept evaluation. They note that it enables participants to scrutinize
products without actually using them; stimulating a retail showroom scenario and enabling immediate gut reactions to be identified. Langford and McDonagh (2003, p. 24) also highlight, however, that the method does not provide true insight into the problems encountered with the product in question during actual use. Within this research, Product Handling enabled the participants to form gut reactions to the fabrics from both visual and tactile perspectives. It was also a means of immersing the participants within the subject at hand and allowed them to form ideas and opinions before discussion began. It was also felt that this method reflected how professionals view fabrics at trade fairs and in showrooms. Following product handling the fabrics remained accessible to participants for reference purposes throughout the discussion.

8.2.4.3 Response Sheets
In addition to audio-taping, response sheets were used in both groups to capture information relating to specific fabric samples and to ensure that each participant's views were documented. During the product handling process the participants were asked to complete the sheets.

8.2.4.4 'Dot Voting'
'Dot Voting' can be used in focus groups to gauge the relative popularity of the products, ideas or design concepts under discussion (Langford and McDonagh, 2003, p. 222). The outcomes can be used to help stimulate further discussion and it is suggested that participants gain some form of tangible result from the activity. Within the first group, each participant was given a number of red and green 'dot' stickers. During the product handling and response form stage of the group, participants were asked to stick their green stickers on those fabric samples they considered successful and red stickers on those they considered unsuccessful. These fabrics were then collated to form the basis of further discussion.

8.2.5 Analytical Technique
The technique used to analyse the data generated from the focus groups followed the analytical procedure outlined in Chapter 3. This involved the three key activities of data reduction, data display and verification. Within this framework the technique used to analyse the focus groups drew on Bruseberg and McDonagh’s (2203, p. 41) comments that much focus group analysis consists of transcribing ideas and thoughts from various forms of documentation, arranging comments into suitable groups and identifying themes and categories relating to user responses. Bruseberg and McDonagh (2003, p. 41) suggest that this process need not be overly extensive involving verbatim transcriptions or discourse analysis but should aim to capture the 'essence' of the discussion. They do, however,
highlight that this process needs to be undertaken by the researcher her/himself as it requires an understanding of the research issues under investigation (2003, p. 98). Within this research, summarised transcriptions from recordings and response sheets were made. Following transcription a ‘Category Analysis’, as described by Bruesburg and McDongah (1997, p. 43), was carried out. This was done in the following way: (1) ideas and comments from the summarised transcriptions were grouped under the ‘discussion headings’ from the moderators guide and response sheets; (2) under each of these headings, key themes were identified and supplemented by the specific comments made during the discussion and on the response forms (3) to gain an idea of the importance of each of the themes, the frequency of specific comments was noted (where strong agreement with a participant’s comment was made by other participants through gestures or affirmative language, the relevant comment frequency was increased by one and; (4) when a specific fabric sample was referred or noted by a participant, the number of the fabric was noted. An example of the category analysis produced is shown in Appendix 9.

8.2.6 Results and Discussion
The results are discussed here under the themes developed within the moderators guide. To keep the discussion consistent, the results are explored in relation to the overarching analytical framework of ‘method’, ‘aesthetic’, ‘associations’ and ‘use’. In order to draw broader meaning from the results, relevant theoretical ideas relating to craft and industry that were outlined in Chapter 2 will be drawn upon in the discussion.

8.2.6.1 Aesthetic

Initial Responses
The participants’ initial responses to the fabrics suggested that they had tactile appeal. Participants in both groups commented that the fabrics ‘prompted touch’ and that the tactile nature of the fabrics was predominant throughout. The fabrics were described as varying from soft to crunchy. It was also noted, however, that the fabrics had the same ‘feel’ throughout. The visual qualities of the fabrics were commented upon less in the initial stages of the discussions, but the tendency of participants to instantly want to hold the fabrics to the light was noted.

Following the initial stage of the discussion participants were asked to discuss in more detail the aesthetic qualities of the fabrics. Key themes within this discussion were categorised separately under the headings ‘tactile qualities’ and ‘visual qualities’.
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Tactile Qualities

Six main discussion themes were developed in regard to the tactile qualities of the fabrics. These included: weight, handle and surface; fabric consistency; embedded materials and decorative finishing; three-dimensionality, delicacy and fragility and; emotional responses.

Weight, Handle and Surface

The contrast between soft and stiff samples was highlighted. It was suggested that softer fabrics had more tactile appeal than those that were stiff. In both focus groups it was highlighted that the actual handle of the fabric did not always correlate with participants' visual perception of the fabric handle. It was suggested, however, that the visual appeal of the fibres used added to the fabrics' tactile appeal. In relation to this, the delicate and fragile appearance of the fabrics was referred to on a number of occasions, in particular, a response of caution in handling such fabrics. The softer fabrics were described as being warm and comforting. This comforting quality was linked to a sense of familiarity, which was prompted by the fabrics' felt like quality. Certain fabrics were described as having a 'pressed, over-washed and ironed' quality which it was noted provoked a sense of comfort and familiarity. This suggested that associations with felt could be considered as a positive aspect of the fabrics, aiding this sense of familiarity which, as Papanek highlights may lead to a higher value being attributed to the fabrics. And, as Rees highlights might prompt users to link products with a particular production method thus providing a further connection between user and product.

When asked about the variation within the collection from a tactile perspective, variation in regard to weight and density was noted. In regard to fabric surface, however, a number of the participants suggested that the fabrics generally had the same 'feel'—'smooth and felted'. When questioned, they noted that the use of different fibre types did not provided obvious variation in surface quality. Others within the group considered there to be a sense of variation in surface quality but that it was as distinct as the variation apparent between different types of woven cloth. This highlighted the limitations of the nonwoven processes that had been employed to create visually different fabric structures. As highlighted later in the discussion, it was noted that finishing processes, such as embossing, are needed to create variety in terms of fabric surface. Contrasts between rough, delicate and smooth surface qualities were noted, however.

Fabric Consistency and Structure

The term 'consistency' was used by the participants to describe the essential structure and quality of the fabrics. Although the essential structure of the all the fabrics was the same in the sense that they were all constructed in the same way, it was suggested that some fabrics
had a greater sense of 'structure' than others. It was suggested that where the structure was 'less obvious' the fabrics were less like conventional felts. Some participants were drawn to the 'unstructured' fabrics and suggested that these had more potential within decorative applications. Other participants, however, perceived fabrics in which the fibres were more obviously integrated as successful in terms of consistency. Such fabrics were perceived as 'tougher' and thought, by some participants, to be more successful due their perceived durability and strength.

**Embedded Materials and Decorative Finishing**

The impact that embedded materials had on the surface quality and structure of the fabrics was noted within the discussions. It was suggested that additional yarns, when used in large quantities, gave the fabrics a greater sense of structure and almost the impression of being woven. It was also noted that where yarns had not been fully encapsulated by the top layer of web an interesting surface effect was achieved.

The impact that the various decorative finishing processes had on the surface quality of the fabrics was also discussed. It was noted that a greater sense of three-dimensionality within the surfaces would create a greater sense of variation in regard to surface. This suggested the need to pursue embossing processes further. The effects created by laser cutting and etching were highlighted but it was suggested that these were not always noticeable due to the amount of other things going on within certain designs.

**Emotional Responses**

As highlighted above, a sense of comfort and familiarity was provoked by some of the fabric samples. Further to this, the fabrics were described by some participants in a way that related to an appreciation of the fabrics beyond formal qualities. Words such as, 'ageing', 'evolving; fragmentary; masculine and feminine were used.

**Visual Qualities**

Under the heading 'visual qualities', the results were categorised under the following themes: embedded materials, layering, complexity/simplicity, overstatement/understatement, pattern, imagery and scale, colour and interaction with light.

**Embedded Materials**

The effect of embedded fabrics, filaments and yarns on the appeal of the fabrics, was one of the most discussed points within each focus group discussion. This suggested that this intervention within the carding process added interest and potential appeal to the resulting
fabrics. The discussion related to the nature of the embedded materials themselves, their integration into the fabric structure and the effects achieved when combined with finishing processes.

The nature and quality of the embedded materials impacted upon the perception of the fabric as a whole. For example, the use of metallic filaments was perceived as pretentious and ‘tacky’ by some but by others it was considered as a means of adding ‘superficial value’. The use of natural matter (dried flowers and leaves) prompted strong associations with handmade paper but when combined with ‘technical processes’ was perceived as interesting. The decaying nature of such materials was suggested as a potential means of conveying concepts and meaning relating to memory and conservation.

Yarn and threads were a predominate material within body of fabrics and so generated a substantial part of the discussions. It was noted that the use of yarns was a potential means of drawing the viewer into the fabric. On the other hand, particularly when used in combination with pattern, yarns and threads were considered a distraction within the design. It was suggested that the yarns worked best when they created a sense of movement, suspension or structure within the fabric. It was noted that such effects were highlighted when the fabrics were viewed to a light source. Although the sense of yarns ‘wandering’ was noted as a successful effect it was suggested that the use of yarns needed to be more controlled in order to avoid a ‘messy’ look.

Layering

The process of layering fibre webs is an essential part of most nonwoven construction methods. Methods of layering or combining various nonwovens following production are commonly used to produce composites. This concept was explored within the collection as a design technique. The success of this technique in developing appealing designs was discussed in each of the groups. The discussions focused on the extent of layering and the use of colour and pattern.

The use of multiple layers within the fabrics was noted by some participants as ‘too much’ as it created a sense of over-complexity and one participant thought that single layers of fabric worked better than those that were layered as they had a more sophisticated feel. Other’s perceived that multiple layers worked well but more attention was needed in regard to the way in which colour and pattern had been combined, in particular, to secondary patterns created by layering laser cut fabrics. It was also noted that the use of contrasting coloured layers within single samples could have been taken further as a design tool.
From a more conceptual perspective it was noted that the sense of layering within the fabrics provoked notions of memory and loss. From a technical perspective, it was noted that fabrics in which layers had been more fully integrated had a greater sense of structural integrity.

**Complexity/Simplicity, Overstatement/Understatement**

Ideas surrounding notions of complexity and simplicity within the designs formed an important part of the discussions. In regard to fabrics from the first two periods of design development work, a sense of complexity was perceived as a prominent aspect of the designs. It was noted that this created visual stimulation and a sense of intrigue but that such complexity would need the right product context to work successfully. Further to this, it was suggested that overall, too many techniques had been used in single fabrics which resulted in overcomplicated designs. It was thought that production techniques and finishing processes had been combined too obviously and it was suggested that where the combinations were less obvious the designs were more successful. Some designs were, however, considered as too simplistic with nothing to draw attention to them.

In contrast to this discussion, a sense of understatement and subtlety within a number of the designs was identified. This was noted in relation to the structural quality of the fabrics and the less explicit manner in which images and surface manipulation techniques had been combined. The ‘subtle’ designs were preferred by most participants and it was noted that these designs had a greater sense of intrigue about them. It was suggested that such designs provoked a sense of the ‘ethereal’ and the ‘aquatic’ and that this was how the fabrics ‘worked best’. It was noted during the second focus group, however, that an ‘overstated’ quality was achieved in certain designs by the bold, large scale shapes which had been created by the use of yarns. These designs were thought to have potential within the context of a balanced design collection.

**Pattern, Imagery and Scale**

The use of pattern and imagery was discussed. The discussion covered issues that related to the use of pattern in general (style, repeat, and scale) but also covered issues relating specifically to the application of pattern to nonwovens. These issues included the use of historic imagery, print quality, the use of laser cutting and the qualities achieved using devoré.

In regard to the style of pattern, it was noted that the use of hand drawn florals imparted a more sophisticated edge to the fabrics than the stylized floral motifs. In regard to repeat, it was suggested that the repeat designs needed further development particularly in regard to the distribution of motifs. It was noted that the designs needed to be viewed as larger pieces or lengths to assess their successfulness as repeat designs. This related to printed and cut
pattern as well as the way in which fabric motifs had been embedded within the fabric structure.

The use of print on nonwovens was considered successful. It was noted that an unconventional printed quality was achieved due to the unevenness of some of the fabric surfaces and where the fabric was too thin and the structure too open to hold a solid colour, it was noted that a decorative effect was achieved. These observations highlight design effects that are perhaps unique to nonwoven structures.

The use of laser cutting to integrate pattern into the fabric structure was questioned. It was suggested that where motifs had been cut with more detail the effect was more successful and, as noted previously, it was highlighted that the secondary patterns created by layering cut designs needed to be more carefully considered. The visibility of some burning around cut edges was identified and was considered a distraction within the design.

The effects achieved by devoré were perceived as creating a ‘faded’ look within the pattern. This was seen as a successful design feature, as was the use of devoré to create a secondary stripe within fabrics. Although it was noted, however, that these stripes were not instantly recognizable. The visual structure created by devoré striping was considered as a successful contrast to the more random striping created by the yarns embedded within the fabrics.

Colour
Within the focus groups, colour was commented upon but not explored in depth. No specific questions were asked in regard to colour but it was a natural aspect of the discussions. Most comments made related to colour preferences, the associations that colour prompted and the ability to blend colour in a unique way within the nonwoven production process.

Within the first focus group the blue/grey and neutral colour schemes were perceived as being more successful than the brighter reds and pinks. It was suggested that the former communicated a more contemporary feel and worked more successfully in terms of tone. The latter were considered too harsh and unsuccessful in terms of tone. It was suggested that the harshness of the reds prompted associations with cleaning products. It was interesting to note that colour was identified during the discussion as a trigger to associations with ‘industrial’ nonwoven products. This highlights the importance of colour in regard to developing nonwovens for new markets within the design sector such as the high-end interiors market.
Within the second group, the green colour scheme was perceived as generally unsuccessful and the beige/brown fabrics perceived as drab. The ecru colour schemes were perceived as positive and described as 'unobtrusive'.

Both groups noted the fading, blending and muted quality of colour within the fabrics as a successful and appealing quality. The use of graduated colour and tone was seen as particularly effective. In relation to this, small scale graduation created by laser etching and devoré was noted as an interesting quality as was the fading and merging of print into the base fabric. It was suggested that these qualities gave the fabrics an ethereal quality and enabled understatement and suggestion within the design. Such comments further suggested the ability to consider and manipulate 'details of surface quality' and visual appearance of nonwovens using the production processes explored to enable fabrics with aesthetic appeal and potential to be realized.

Interaction with Light

The translucent quality of the fabrics was one of the most discussed aspects within both focus groups. The way in which the fabrics interacted with light was considered as an important aspect of the fabric's appeal. Participants noted on a number of occasions that they felt drawn to pick up the fabrics and hold them to the light. One of the key points raised was that light had a 'transformative' effect on a number of the fabrics. It was noted that hidden embedded materials that were not evident when viewing the fabrics in a flat manner, and the intricacies of laser cutting within other fabrics, were revealed when viewed in front of a light source. It was suggested that the fabrics worked best when functioning in this way and that this quality made them distinct from conventional felted fabrics. It was also noted that the fabrics had two different qualities dependent on the presence or absence of light. This was perceived as appealing.

During the second focus group it was noted that the type of light with which the fabric's interacted impacted on the success of the effect achieved. It was suggested that natural light worked better than synthetic light. Although the interaction of the fabrics with light was generally perceived as positive, it was noted that the light emphasized the uneven surface quality and density of some of the fabrics and that when viewed in front of light some of the pattern within the fabrics was lost.
8.2.6.2 Associations

Many of the comments made in relation to the aesthetic qualities of the fabrics suggested certain associational values. To further understand the associational values of the fabrics, participants were asked to note any associations the fabrics prompted with other materials and products. It was hoped that this would enable an indication of whether the fabrics had moved away from the industrial associations that are predominant in relation to nonwovens.

Key themes arising from this part of the discussion were categorised under the following headings, associations with: design based and industrially based products; natural and manmade materials; paper and felt and; cultural and conceptual associations.

**Associations with Products**

Associations, triggered by the use of pattern, were made with contemporary wallpapers and also printed curtains. Some of the heavier fabrics were associated with table settings. However, more associations were made with what might be regarded as industrial products. For example certain lightweight fabrics were linked to cleaning products such as jay cloths. Associations were also made with interlinings and insulations products. This suggested that the predominant associations prompted by the fabrics linked them to industrially based products.

**Associations Prompted by Natural and Manmade Materials**

As in any product, the use of certain natural and man-made materials prompts various associations. The use of goat's hair within certain fabrics prompted associational values relating to cleanliness and the use of lurex prompted associations with '80's fashion'. The use of cellulose prompted associations with cotton wool and the use of trilobal-nylon associations with cotton wool.

**Paper and Felt**

As one would have expected, associations with paper, felts and plastics were made within each discussion. In general, the lighter, stiffer fabrics were associated with paper and the softer denser fabrics with felt. It was highlighted in the first discussion that the identity of the fabrics as 'felt' was not lost. However, in the second discussion it was suggested that, where lots of yarns had been embedded into the fabrics, the fabrics began to move away from traditional papers and felts.
Fabric's in which natural matter and fabric motifs had been embedded prompted associations with handmade papers which it was noted by one participant, created a sense of 'over familiarity'.

**Cultural and Conceptual**

Papanek (1985, p.19-21) writes that 'most associational values are universal within a culture and are frequently based on the traditions of that culture'. A number of associational values linked to cultural traditions were highlighted in relation to the fabrics. These included associations with Japanese design, prompted by the hand drawn floral motifs and the colour and composition of certain designs. The use of lace like patterns prompted associations with historic textiles. In relation to what might be regarded as 'conceptual' associational values participants noted that the fabrics prompted a sense of memory, ageing, fragmentation, comfort and masculinity. This suggested that the fabrics held broader associational values relevant to the design sector.

8.2.6.3 Use–Potential Applications and Possible Limitations

The participants were asked to consider potential opportunities and limitations in regard to the potential end uses of the fabrics. The ideas put forward were grouped into the following categories: furnishing fabrics; surfaces; lighting and window treatments; fashion and; decorative applications.

**Furnishing Fabrics**

Participants suggested that, from an aesthetic perspective, certain fabrics discussed could be suitable for upholstery. Within the first group, however, a number of concerns were raised about the suitability of some the fabrics from a performance perspective. The level of fabric durability and stability was questioned and it was noted that the fabrics might have a propensity to collect dust and dirt.

**Surfaces**

A number of applications relating to two dimensional surfaces were suggested as potential end-used including wall-coverings, table-mats, flat bed panelling and screening. It was suggested that the flat nature of the fabrics would lend itself to such products. Concerns in regard to performance properties were similar to those outlined above, although it was noted that this would be less of a concern in regard to products that would not have to withstand a lot of physical contact during use.
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**Lighting and Window Treatments**

Products that exploited the translucent qualities of the fabrics and the way in which they interacted with light were considered as the most suitable application area. For example, blinds, flat window treatments and light shades. In addition, the potential to use the fabrics on a large scale within this context was noted.

**Fashion**

Some fashion applications were suggested. It was noted that the sculptural properties of the fabrics could be used to produce hats and bags in a similar way to felt. The possibilities to create moulded garments, as well as conventionally produced garments, was suggested and the potential use of the fabrics as linings was highlighted. In regard to performance, concerns about durability were raised as well as the need to improve the fabric handle.

**Decorative and Architectural Applications**

It was noted in both discussions that the fabrics would be appropriate for purely decorative applications such as wall hangings, decorative bed-heads, ornamental cushions and decorative screening. It was also noted that the fabrics might work in architectural settings and could be developed within an ecological product framework due to the ability to utilise scrap fabrics within the fabric production process.

These discussions suggested that, from a purely aesthetic perspective, the fabrics as they stand would be suitable for various applications within the design sector. It was highlighted, however, that the performance properties of the fabrics might limit suitable product areas.

8.2.6.3 Use–Value and Market

Having discussed suitable product applications for the fabrics, participants were asked to consider where they would see the fabrics sitting in regard to current markets.

The themes arising from the discussion were categorised under the following headings: low; mid and mass market; luxury and high-end markets and; craft and bespoke markets.

**Low, Mid and Mass Market**

In discussions one and two, a number of the fabrics were perceived as being suitable for the mid to mass market. It was suggested that the simpler samples had a mainstream quality about them and a there was a sense of mass production about them. However, it was noted that all of the designs could be adapted and geared towards mass production if that was the
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direction in which the work was to be taken. The notion of adding value to something that is mass produced was considered as an interesting idea for future development.

These comments relate to Helen Rees discussion about the ability of the consumer to identify hand and machine made work and the subsequent associational values that are formed. The link between mass production methods and lower value perhaps confirms this notion.

Luxury and High End Markets
It was discussed that the economics of the processes used to produce the fabrics might necessitate a luxury market. This highlighted the requirement for the fabrics to be aesthetically valued as luxury or high-end fabrics. It was suggested that although this value might be recognised by those with a knowledge of textile processes, people with no background in textiles might find it difficult to recognise, therefore, making it difficult to communicate the actual economic value of the fabrics. This underlined the need for the fabrics to communicate value through their aesthetic qualities and perhaps the need for them, as Rees (1997, p. 122-123) points out, to suggest a link with a 'creative individual'.

A greater proportion of the fabrics discussed in the second focus group were considered as suitable for high-end and luxury markets. It was noted that combining processes such as cutting and layering gave the fabrics a sense of the hand made and therefore greater value. In relation to this, it was highlighted that some of the fabrics looked hand-made but lacked the sophistication required to make them high-end fabrics. The use of heavier yarns within the fabrics was noted as creating simple but 'high-end' looking fabrics.

Craft and Bespoke Markets
A number of comments were made in regard to the value and market position of those fabrics that were associated with notions of craft. As outlined in Chapter 2 the notion of craft works within a range of contexts which were highlighted in the focus group discussions. In the first discussion it was noted that certain fabrics prompted a ‘sense of craft’ which was seen as positive leading to associations with designer/maker products. In regard to others, comparisons with cheap hand made products such as paper lanterns were made. The discussion highlighted that, association with the hand made does not, by itself lead to a high perceived value. Sophistication in terms of design is also required. The point was also made that rarity and uniqueness can lead to high value and that some of the fabrics in question could function in this way. Again, it was noted that the expense of some of the processes employed in production might necessitate a bespoke approach.
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A key theme from the discussion of market and value was that the economics of the process to some extent dictate the market in which the product functions. It was also highlighted that the products within high-end markets need to communicate a sense of uniqueness and sophistication in terms of design in order to be appropriate to that market. The discussion revealed that some of the fabrics did have these qualities but that others did not. Those fabrics which were the result of machine interventions and had been further processed in a decorative manner were perceived as having such qualities. Those which were more akin to conventional nonwoven production and associated with cheap industrial products were perceived as not having such qualities.

Further to this it was highlighted that presentation and branding have an impact upon perceived product value and that it is difficult to assess fabrics in isolation from the presentation of a specific product.

8.2.6.4 Reflections on Method
Although the focus groups did provide information in regard to specific fabrics, on reflection the number of fabrics included in the first focus group was too great and made it difficult to keep track of the specific fabrics to which the discussion related. However, the response forms did enable more detailed information about specific fabrics to be captured. The number of fabrics used in the second focus group was reduced which enabled accurate information to be captured and specific comparisons to be made.

8.3 Interviews with Interior Product Design Professionals
It had emerged from the first focus groups that the fabrics were potentially suited to interior applications in particular lighting and two dimensional surfaces. A series of interviews with lighting and wall-covering designers were therefore conducted. The aim of the interviews was to develop further external evaluation on the nonwoven fabric designs that had been developed, in particular, to evaluate the suitability of the fabrics for high-end lighting and wall coverings. Due to the practicalities and expense involved in gathering professional designers together for a focus group, shorter individual interviews were conducted.

8.3.1 Participants
Owing to the aim within the research to develop nonwovens that are suitable for high end markets, all of the design companies approached for participation in the research were all working in the mid to high end of the interiors market and were sourced through the 100% Design trade fair. Five interviews were set up, the first acting as a pilot study. The company
names, descriptions of their design practice and the interviewee’s role within this are described in Table 4.

<table>
<thead>
<tr>
<th>Interview Number</th>
<th>Design Company / Designer</th>
<th>Company Description</th>
<th>Interviewee</th>
<th>Interviewee’s Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot</td>
<td>Paul Caruthers</td>
<td>Design and short batch production of contemporary lighting</td>
<td>Paul Caruthers</td>
<td>Owner/Designer</td>
</tr>
<tr>
<td>1</td>
<td>Max Watt Design</td>
<td>Design and manufacture of lights for top-end domestic and contract interiors. Bespoke and stock ranges.</td>
<td>Tracey Remfrey</td>
<td>Owner and design director</td>
</tr>
<tr>
<td>2</td>
<td>CTO Lighting</td>
<td>Design and manufacture of lights for top-end domestic and contract interiors. Bespoke and stock ranges.</td>
<td>Charlie Swann</td>
<td>Designer</td>
</tr>
<tr>
<td>3</td>
<td>Fred Duthy</td>
<td>Lighting and interior products</td>
<td>Fred Duthy</td>
<td>Owner/Designer</td>
</tr>
<tr>
<td>4</td>
<td>Stereo Wall-coverings</td>
<td>Specialists in materials-based wall-coverings for high-end domestic interiors.</td>
<td>Martyn Bennett</td>
<td>Owner and Design Director</td>
</tr>
</tbody>
</table>

Table 4: Summary of Interviewee Information (Product Designers).

8.3.2 Interview Environment

The interviews were held either at the designers’ studio or office base with the exception of the interview with Stereo, which was held at Chelsea Harbour Design Centre.

8.3.3 Interview Content and Structure

As in the focus groups the discussion contents remained located within the framework of the Papanek’s function complex. The discussion was predominantly focused around ‘aesthetics’, ‘use’ and ‘associations’ aspects and ‘method’ aspect was also touched upon. The aim of the discussions was to get a more specific idea of the fabric’s suitability, both aesthetically and technically, for interior lighting and surfaces.

The interviews were structured in that there was a clear and planned development of discussion topics. This was established by using a ‘moderator’s guide’ as discussed in section 8.2.3. However, the researcher was open to the discussion of alternative topics, if relevant to the research, when they arose. Like the focus groups, the interviews were structured using a funnel approach as discussed in section 8.2.3. The first part of the interviews were designed to gain more in-depth information on the design practice of the interviewee to enable the discussion to be placed in context. Questions related to their
design aims and strategies, the market in which they operate, their client base, their use of materials and manufacturing processes. The interviewee's were also asked about how they select new materials and the importance of aesthetic or technical criteria within their selection process. Following these initial questions, the interviewee's were then asked to view and handle a portfolio of the fabrics and to give their initial response. Further questions were then asked in regard to associations that fabrics prompted and the suitability of the fabrics for lighting and interior surfaces. In summary, the interviews were structured as follows:

- questions relating to interviewee's design practice;
- questions relating to interviewee's selection of new materials;
- fabric viewing, handling and responses;
- questions relating to associations and;
- questions relating to the suitability of the fabrics for lighting/surfaces.

8.3.3.1 Fabric Selection
A selection of twenty fabrics was selected by the researcher from the first two periods of design development. The fabrics selected were those the researcher considered most successful in light of her own reflective analysis whilst taking into consideration the comments made in the focus groups. The fabrics selected are listed Appendix 8.

8.3.4. Documentation and Interview Tools
8.3.4.1 Audio-Taping
The interviews were recorded using audio-taping (as discussed in section) and the researcher also took notes during and immediately after each interview.

8.3.5 Analytical Technique
The technique used to analyse the information and feedback gained in the interviews remained consistent with that used in the focus groups as discussed in section 8.2.5. Summarised transcriptions of the recordings were made and a Category Analysis consolidating the information from the four main interviews was made.

8.3.6 Results and Discussion
Before outlining the comments made during the interviews in regard to the fabrics in question, background information relating to the design company's products, markets and use of materials is outlined. The interviewee's responses to the fabrics will then be outlined followed by an outline of the discussion relating to the suitability of the fabrics for use within lighting
and wall-coverings. The comments made in regard to the fabrics will be explored in relation to the overarching analytical framework of ‘aesthetic’, ‘associations’ and ‘use’. Within these headings the following categories were used to structure the analysis: tactile qualities; visual qualities; associations and; suitability for lighting and wall-coverings. Specific themes were developed under each of these categories. In order to draw broader meaning from the results, relevant theoretical ideas relating to craft and industry that were outlined in Chapter 2 will be drawn upon in the discussion. When comments were made in relation to specific fabrics, the fabric number is noted in brackets.

8.3.6.1 Designers’ Background Information

Products and Market
As highlighted in Table 3, each of the interviewees designed products aimed at the mid to high end of the interiors market. Interviewee 1 and 2 both produced a range of lighting solutions for domestic and contract interiors ranging from traditional drum and box light shades to sculpted paper shades and sculptural lights made from glass and plastic. The wall-covering company interviewed specialised in ‘materials based’ products, for example wall coverings made from grass-papers, linens and silks.

The first two designers interviewed provided a bespoke design surface alongside a stock range of products which they manufactured themselves. Their main client bases were interior designers and specifiers working on residential interiors as well as hotels, bars and other contract environments. The third lighting designer worked predominantly on the design of prototype products that were then sold on to retailers such as Habitat who then put the designs into production. The wall-covering company interviewed had a continually developing portfolio of wall-covering samples manufactured by various specialist companies. The main market for these products was very high-end residential interiors.

Use of Materials
The interviewees were asked about their use of materials and in particular the criteria they used for selecting fabrics. It became clearly apparent that none of the designers worked with rigid criteria but more with a sense of priorities that related to their product and market. The discussion surrounding this was grouped into the following categories: aesthetics; cost and market requirements and; technical and performance requirements.

Aesthetics
Each of the designers interviewed said that aesthetic requirements were a priority when selecting materials. In regard to lighting, perhaps obviously, the main requirement was that the material filtered light effectively and ‘looked good’ when functioning in this way. Two of the designers highlighted the need for fabrics to have an even consistency and to be opaque...
enough to shield the light bulb when required. The requirement of the fabric to look good when the light source is both on and off was noted. The tactile qualities of the materials were also highlighted as an important factor. It was noted by one designer that the materials needed to have a distinct and appealing tactile quality.

In regard to wall-coverings attention was drawn to the need for a smooth surface and it was highlighted that good design was essential within high-end markets particularly in regard to the use of colour and the consideration of the interior environment as a whole.

**Cost and Market Requirements**

In interviews one and four it was noted that, within the high end interiors market, clients can often be conservative about the materials which they choose to have in their homes. This can therefore limit the range of materials that are used. This conservatism was thought to be due to certain associations of quality and value that are attributed to traditional materials such as cottons and linens. It was noted that it is often difficult to convince clients within this market to use more experimental or contemporary materials.

Further to this it was suggested that, owing to the niche nature of this market, fabrics have to be economically viable when produced in small volumes. One of the interviewee’s, who had experience of working with nonwovens, perceived that using nonwovens within niche markets is essentially problematic due to the small demand in regard to volume but the necessity for mass manufacture in production. The costing of the fabric therefore impacts upon whether or not it is selected for a particular range. In relation to this the designer, in interview two who was working with retailers, noted that materials must be relevant to mass manufacture and that the final selection of materials used is negotiated with the retailer and their manufacturer and based on their various requirements. These comments highlighted the importance of considering manufacturing opportunities and limitations in regard to developing design led fabrics. In contrast to this, however, the designers in interviews one and three suggested that the ‘look’ of the fabric drives selection and the costing is built around this.

**Technical and Performance Requirements**

In all interviews there was a sense that consideration of the technical and performance requirements of fabrics was discrete rather than explicit. The main priority in this area related to avoiding obviously unstable or flammable materials.

In regard to wall-coverings it was noted that, within the top end of the market, performance requirements are a secondary issue and that design from an aesthetic perspective is seen as the primary importance. It was suggested, however, that any level of technical performance
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is an advantage. Resistance to splashes to avoid the need for extensive cleaning was noted as a desirable performance property which can often be achieved through the use of a protective coating. In regard to lighting product care and cleaning were not considered as essential considerations within these product contexts. It was suggested that materials need only to withstand dusting and gentle rubbing with a damp cloth. In interviews one and three, products such as light shades are not always required as permanent fixtures and are therefore not expected to withstand years of wear and tear.

The designers in interviews one, two and three were aware of the performance properties of traditional fabrics such as silk and linen and therefore they did not require specifications in regard to performance properties when selecting fabrics. There was a sense that an intuitive approach to this aspect of selection was taken. It was noted that working with established fabric manufacturers and suppliers means that performance issues are dealt with before the designer comes into contact with them. This suggested the potential need to provide a fabric specification when developing unconventional or new fabrics for use in this area in order to reassure product designers.

Although fabric specifications were not sought within this product area, it was noted that the final products are heat tested in relation to the strength of light to be used and the distance of the shade from that source. Further to this it was highlighted in interviews one and two that fabrics are often laminated to a PVC layer which adds a layer of resistance. In relation to fabric durability the requirements were again, not explicit but it was suggested that the fabrics needed to be tough enough to endure the manufacture of the final product without being damaged. In the production of shades it was noted that fabrics are required to withstand pulling and tensioning. It was noted that if a fabric can be suitably backed then the application possibilities are widened.

8.3.6.2 Aesthetic

The responses to the fabrics in regard to aesthetics were categorised in regard to tactile and visual qualities.

**Tactile Qualities**

Comments that were categorised as relating to the tactile qualities of the fabrics dominated the discussions. These comments were developed into the following themes: delicacy and fragility; weight and consistency and; descriptions relating to surface and handle.
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Delicacy and Fragility
The delicate and fragile nature of the fabrics was the most highlighted aspect in regard to the tactile qualities of the fabrics. This was seen as a concern in regard to using the fabric in the production of light shades (DD5, DD4 and DD3). It was suggested that they may be too delicate for production and may not adequately mask a PVC backing (as used in a number of the designer’s products). The fineness of the fabrics in relation to their ability to hold embedded materials was, however, noted as an interesting quality.

Weight and Consistency
The consistency and thickness of some of the fabrics was described in the first two interviews as ‘uneven’ (DD2). This was perceived as potentially problematic in regard to the manufacture of light shades because a consistent level of strength is required to enable smooth manufacture. The tapered quality at the edge of some of the samples which was created by a gradual reduction in fabric thickness was, however, seen as a positive aesthetic quality.

Surface and Handle
Comments relating to handle, included descriptions of specific fabrics as ‘spongy’ (DD2), ‘plastic like’ (DD1) and as feeling ‘lovely’. In regard to surface quality, some of the fabrics were referred to as being ‘hairy’ (DD1 and DD56). Within the context of wall coverings this quality was perceived as undesirable. The use of goats hair within the fabrics was also perceived as inappropriate within an interior context owing to the associations it holds (DD55). The three dimensional surface quality created by embossing was highlighted in the first interview and described as ‘bubbly’ (DD40). This was seen as a positive quality.

Visual Qualities
In regard to visual qualities the discussion focused the following themes: fabric transparency and interaction with light; layering and embedded materials and; pattern.

Transparency and interaction with light
The transparency of the fabrics and the way in which they interacted with light was obviously an important factor in regard to the fabrics suitability for lighting. The designer’s singled out two or three fabrics that they though worked particularly well in regard to the effects achieved when held to a light source (DD1, DD40, DD48, DD6). It was noted that the way in which light drew out the pattern in certain fabrics was interesting (DD48). During the first three interviews it was suggested that for a fabric to be effective within a lighting product it needs to look good.
The transparent nature of the fabrics was noted as a positive feature (DD2, DD38 and DD6). This related to the way in which the fabrics interacted with light but also to the sense of depth created by being able to see through the top layers of fibre to those below. The interaction that this created between the background and foreground was noted as a successful design feature (DD6). From a less positive perspective it was suggested that some of the fabrics were possibly too transparent and might reveal any backings that would need to be used in manufacture (DD39). It was noted that this may cause a problem if design required the light bulb to be completely concealed and in regard to wall-coverings it was noted that it may be difficult to back such fabrics without losing the sense of depth created by the translucency of the fabric layers.

Layering and Embedded Materials
The way in which materials had been embedded within the fabric samples was noted as creating an ‘illusive’ quality and a sense that the design was beneath the surface (DD2, DD48 and DD5). The ability to support materials between layers was thought to be a unique design feature and was described as creating a ‘hidden’ quality. In regard to the fabrics’ potential as wall-coverings it was suggested that this feature would be a key area of interest. It was highlighted that it was the ‘encapsulated’ materials that provided this interest not the background fabrics themselves. In regard to the composition of the embedded materials, the possibility to arrange the materials in more ‘uniform arrangements’ was questioned. The use of layering laser cut fabrics onto a solid background was also highlighted as a successful technique but it was noted that the simpler the approach to this the better (DD48).

Pattern
The use of pattern was considered as being particularly interesting when drawn out by light through the use of devoré. Although the use of laser cutting had been noted as successful the distraction of some singeing on cut edges was noted. It was highlighted, however, that the success of pattern is often trend dependent.

8.3.6.3 Use
Suitability for Lighting and Wall-coverings
During the discussion that took place whilst the interviewees were looking through and fabrics there was a clear sense that, from an aesthetic perspective, they considered that a number of the fabrics could be used successfully within lights. There was also a sense of concern,
however, about the consistency of the fabrics, their durability and surface quality in relation to the product manufacturing process and in final use. In regard to wall-coverings, a number of points for development and consideration within each of these areas were also highlighted.

Fabric Consistency
The uneven fabric consistency of some of the fabrics was highlighted during interviewee’s one and two as a potential concern (DD2 and DD1). It was suggested that the subsequent unevenness in terms of strength would create a problem in the pulling and tensioning processes required to make a shade. In regard to the final look of the product, there was concern that the uneven consistency might create a ‘patchy’ appearance when the light was on. It was also noted that the thinner areas of the light might be too transparent creating a harsh lit effect and possible showing the light bulb. However, it was noted that were the fabrics successfully laminated to PVC backing this might not cause a problem. It was suggested that most of the fabrics, with the exception the very fine fabrics, would be backable in this way.

Strength and Durability
The strength, toughness and durability of the fabrics were questioned in all of the interviews. It was noted that there was a variation in regard to strength within the collection. Most of these concerns arose in regard to the thinner, more delicate fabrics. It was noted that the strength at the thinnest part of the fabric would have to be considered as the overall strength of the fabric in regard to assessing its suitability for the making up process. Whether or not the fabric could withstand being pulled around a frame without tearing was questioned. However, it was suggested that such fabrics could be used for specific projects but would require special considerations in regard to making up. The stability of the embedded materials within the fabrics was also questioned as it was noted that certain elements could be peeled away from the surface. It was noted, however, in interviews one and two that if the fabrics could be laminated to PVC there would be no real concerns in using them. The need to back the fabrics was also highlighted in regard to wall-coverings. As noted previously, concern was raised that in doing so some of the appeal of the translucent qualities within the fabrics might be lost.

Surface Quality
The durability of the fabrics surface quality was questioned. The designer in interview one wanted to know if the fabric surface ‘bobbed’ and in regard to wall-coverings it was suggested that the fabrics would need a splash proof finish.
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Value and Market
When the interviewees were asked what they perceived the value of the fabrics to be, the responses were similar to those given in the focus groups and related to both the high and bottom end of the market. Within this, the value placed upon traditional materials within high-end markets was highlighted in comparison to 'new' fabrics.

Traditional Material Value
All four designers raised noted the value placed on traditional materials within the markets in which they worked. The main thread of the discussions was a reiteration that consumers place a high value on traditional materials such as silk and cotton. It was suggested that consumer familiarity with such materials and the associations with quality that they place upon them are strong. It was highlighted, from the designers' experience, that even if products made from such materials are cheaper in cost than a new or experimental material they are still valued more highly.

Drawing on his experience of working with nonwovens the designer in interview three confirmed that consumers prefer traditional materials, particularly at the very high end of the residential interiors market. He suggested that this was due to their desire for quality and a constrained, non-radical approach to design no matter how contemporary the material. The interviewee noted that the nonwovens do not sell in the same volume as the other materials and suggested that this was because of their hard, cold appearance and the fact that they have no former traditional material value attached to them. It was also noted, in his experience, consumers not know about or understand nonwovens and therefore do not attribute the same level of value to them that they would with silk, cotton, linen or suede. The interviewee went on to say that within his collection an attempt had been made to visually soften the nonwoven designs. However, he suggested that it would be very difficult to communicate nonwovens as craft or luxury materials because in essence they are not – he described them as a 'funny material' and that most people 'don't know what to make of them'.

In interview one it was suggested that if nonwovens contained some silk or cotton, or had silk thread running through them they would probably be more highly valued. In regard to the use of natural materials it was suggested that the use of natural fibre in the fabrics if recognisable and aesthetically pleasing could add a sense of value to them. In contrast to the value that is placed upon traditional materials by consumers, it was noted in interview three that, if materials have an association with cheap materials such as cleaning wipes a customer will never be prepared to pay a high price for the product no matter how extensively it has been manipulated.
These comments relate to Rees (1997, p.122–123) discussion relating to the value that customers put on industrially produced products and those produced by a 'creative individual'.

The discussion suggests that the nonwovens that are present in current markets reflect their industrial roots. This highlights the requirement for nonwovens that show a different approach to their production.

**High end Fabrics**

Although much was said in interview three about the difficulty of imbuing nonwovens with traditional value, it was noted in the first two interviews that the fabric collection in general had a 'luxurious feel' and were 'expensive looking' or had an 'affluent quality' about them, in particular the thicker fabrics within the collection. It was highlighted in interview two that this luxurious quality was achieved by the way that the fabrics had been treated rather than the material itself. This pointed to the importance of developing innovative finishing and decorative processes in regard to nonwovens for high-end markets. It was suggested that the thinner fabrics, however, had a cheaper look to them.

The cost implications of producing nonwovens for the high-end was identified in interview three as problematic. It was highlighted that the high end of the market is often niche, and that volume is rarely required. The interviewee noted that his knowledge of nonwoven manufacturing was that it worked on the basis of very high volume making. This, he noted, suggested that it may be difficult to marry nonwovens, from an economical perspective, to the high end market.

8.3.6.4 Associations

In regard to associations, it was highlighted that the associations formed with the fabrics would partly depend upon the design of the final product. Throughout the course of the four interviews, however, associations relating to the fabric samples were made and included: cultural associations; associations with industrial materials and; paper, felt and plastic.

**Cultural Associations**

Prompted by the effect created by embedding materials with the base webs, associations were made with Japanese screening.

**Paper, Felt and Plastic**

During interview two almost instant associations were made with paper and plastic in regard to the handle of certain fabrics (DD2 and DD1). Associations with handmade papers were
also prompted by the use of dried plant materials within the base webs. In regard to felt, certain fabrics were described as 'feltly' on a number of occasions within the four interviews (DD6 and DD11) and the collection as a whole was described by one designer as 'luxurious felt'.

**Industrial Products**

In interview three, the heavier viscose fabrics (DD5 and DD6) prompted associations with the fabric used to cover snooker tables and with jay-cloths. It was noted that the 'structure' of the fabric was reminiscent of dish-cloths. In regard to these associations, as highlighted above, it was suggested that if associations with a cheap material such as a cleaning wipe is made by a consumer then are not likely to pay a high price for the product no matter how extensively it has been manipulated.

The comments in regard to associations revealed that although a number of the fabrics were perceived as being of high value, a number did not lose their associations with traditional low value nonwoven products. This highlighted the requirement for continual development in regard to the aesthetic qualities of nonwovens, in particular their associational value.

8.4 Interviews with Nonwoven Manufacturers

The research questions set required the possibility to produce the fabrics within the context of industrial nonwoven production to be explored. Having practically developed and explored design concepts using hand based and using pilot scale industrial nonwoven equipment, the interviews aimed to explore the potential to develop the ideas on a larger manufacturing scale. The intention was that this would provide negotiated outcomes to be developed in terms of the research outcomes.

Following the initial focus groups, a series of interviews with nonwoven manufacturers were set up. The interviews took place after Stage 2 of the practical. Owing to the practical problems involved in getting groups of industry professionals together to form focus groups, a series of interviews were conducted instead.

8.4.1 Participants

Three interviews were conducted with representatives from nonwoven manufacturing companies whose processes related to those used within the practical research. Companies who used either or both carding and calendar bonding were selected. Further to the interviews correspondence also took place with a fourth company but no formal interview was conducted. Each of the companies were sourced through the Nonwovens Network Database (Nonwovensnetwork.com, 2005). The details of each company are given in Table 5. Due to
requirements regarding confidentiality the company names are not given. To avoid confusion with the previous interviews, these interviews are numbered 5–8

<table>
<thead>
<tr>
<th>Interview/Correspondance Number</th>
<th>Company Description</th>
<th>Nonwoven Manufacturing Processes Employed</th>
<th>Interviewee(s) Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Company produces unique nonwovens using novel spun-laid processes and bi-component fibres. Product application areas including backing for flooring/carpet (32% of output), geosynthetics (26%), roofing (25%) and automotive products (17%), decorative applications.</td>
<td>Novel Spun-laid Process (incorporating calendar bonding process)</td>
<td>UK Sales Manager</td>
</tr>
<tr>
<td>6</td>
<td>Producers of cost effective high performance intelligent fabric systems for niche markets. Products used in medical, automotive, sports and leisure, military (protective clothing), civil defence and humanitarian relief (used in shelters) industries.</td>
<td>Point bonding (of pre-consolidated webs to produce composites)</td>
<td>Director of R+D</td>
</tr>
<tr>
<td>7</td>
<td>Company produces specialist technical nonwoven fabric for comparatively niche markets. Also offers customisation services. Applications include automotive, medical and interlinings.</td>
<td>Carding Thermal bonding (calendar) Chemical bonding Hydro-entanglement</td>
<td>Head of R+D Head of Technical Head of Business Development</td>
</tr>
<tr>
<td>8 (correspondence)</td>
<td>Production Nonwovens using nylon and polyester bi-component fibres. Fabrics are used predominantly in footwear. Wide range of colours and surface textures available. Fabrics can be printed or coated</td>
<td>Carding and Point Bonding</td>
<td>Assistant to Operations</td>
</tr>
</tbody>
</table>

Table 5 Summary of Interviewee Information (Nonwoven Manufacturers).

8.4.2 Interview Environment
The first two interviews were held at the company's manufacturing sites. Conducting the interviews on site enabled the manufacturing processes specific to each company to be observed enabling a greater depth of information and understanding to be gained. The third was held at a company's UK sales office.
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8.4.3 Interview Contents and Structure

The discussion remained located within the framework of Papanek’s (1985, p.7) function complex. The aim of the interviews was to generate feedback on the potential to transfer the ideas embedded within the fabrics to larger scale manufacturing. The discussions focused predominantly, therefore, around the function of 'method'. As previously, the interviews were structured as there was a clear and planned development of discussion topics (developed using a ‘moderators guide’ as discussed in section 8.2.3). However, the researcher was open to the discussion of alternative topics, if relevant to the research. Like the focus groups, the interviews were structured using a funnel approach (as discussed in section 8.2.3).

At the start of the interview a brief outline of the research and interview aims was given via a Power Point presentation. Having outlined the research the interviewees were asked questions regarding the company’s background, manufacturing processes, the products produced, the volume in which they produce them and the markets in which they operate. The interviewees were asked to view and handle a small portfolio of fabric samples. Questions were then asked about the possibility to achieving the design effects shown in the fabrics using the company’s own manufacturing processes. The feasibility of developing such ideas was then discussed. In summary, the interviews were structured as follows;

- Outline/presentation of research and interview aims and objective
- Questions relating to company background and activities
- Fabric viewing and handling
- Questions relating to fabric effects achievable using the company’s processes
- Questions relating to feasibility of producing fabric ideas/transferability of ideas to larger scale production and collaborative possibilities

8.4.3.1 Fabric Selection

A small selection of fabrics from the first two stages of the practical work was selected by the research. The selection represented each of the design concepts being developed. A list of the fabrics is given in Appendix 8.

8.4.4 Documentation and Interview Tools

Due to the requirements of confidentiality, the interviews were not recorded. Therefore the main mode of documentation was note taking during and immediately after each interview.
8.4.4.1 Immersion and Warm up Tools

During the interviews a number of tools were used to initiate and develop discussion.

Langford and McDonagh (2003, p. 177) note that when conducting focus groups it is useful to use ‘immersion’ or ‘warm-up’ tools. They describe that such tools can be used prior to the discussion or at the start of it. The tools can serve to prepare participants for the discussion so that they have an awareness of the issues that will be discussed, are tuned into the subject in question and are actively thinking about the issues. Within this stage of the research ‘Interview Proposals’ and ‘Power Point Presentations’ were used as immersion tools.

**Interview Proposals**

On agreeing to take part in the research, each interviewee was sent an 'Interview Proposal'. This was a short document outlining the research project, the aims of the interview and the areas that would be discussed at the interview. The purpose was to enable the interviewees to think about the issues at hand before the interview and to prepare any relevant information.

**Power Point Presentation**

Further to the Interview Proposals a Power Point Presentation was prepared and delivered in a low key manner at the beginning of each interview. The aims of this were to further clarify the subject of the interviews, raise the interviewee's interest in the subject and enable them to fully tune in with the subject at hand. Langford and McDonagh (2003, p. 205), describe such methods as 'Visual Evaluations of Products or Systems' which provide 'valuable stimulus for discussion'.

8.4.4.2 Sample Handling

As in the previous set of focus groups and interviews sample handling formed an important part of the interview (as discussed in section 8.2.4.1).

8.4.5 Analytical Technique

The analytical technique used was the same as that used in the previous focus groups and interviews (as discussed in sections 8.2.5 and 8.3.5). The Category Analysis that was developed is shown in Appendix 15.

8.4.6 Results and Discussion

The discussion and comments made within the interviews were located within the 'Method' aspect of the function complex model. Within this the following categories were used to
structure the analysis: commercial and manufacturing viability; design capabilities and; translation of designs. In order to develop the themes arising from the discussions the relevant theoretical ideas relating to craft and industry that were outlined in Chapter 2 will be drawn upon in the discussion. When comments were made in relation to specific fabrics, the fabric number (as listed in Appendix 12) is noted in brackets.

Before the categories within the 'method' aspect are discussed, information relating to the company's markets and their awareness of nonwovens in design will be outlined.

8.4.6.1 Company Markets and Awareness of Design
All but one of the companies functioned primarily within the industrial and technical sectors of the nonwovens market. The first company interviewed was the only one producing nonwovens specifically for a decorative market area. It was noted, by the interviewee, that although this market is comparatively small in relation to the technical markets, product development in terms of design is taking place to meet the needs of the market. Owing to this company's involvement within this market area, the interviewee was aware of various nonwoven products produced for the design sector, for example nonwoven wall-coverings, and the use of industrial nonwovens in couture fashion.

It was highlighted by two of the manufacturers that, owing to the markets in which they operate, the aesthetic and decorative aspects of their products are not usually a concern or a priority. Further to this they were not fully aware of the growing use of nonwovens within design sectors (12, 13). Each of the manufacturers, however, cited products which they produce that have an aesthetic or decorative aspect about them. For example the production of wipes and linings that have an embossed pattern on them or the use of print to add a sense of value to high quality technical products such as roofing insulation.

The manufacturers emphasis of their priorities in terms of product and market pointed to Yair's discussion of 'contextual fit' in regard to craft/industry collaboration, discussed in Chapter 2. It perhaps accounts for the difficulty experienced by the researcher in forming suitable collaborations with industry. Through discussion with manufacturers, however, it became evident that some of their products do consider aesthetics and it is more likely the market in which they operate that creates the lack of 'fit'.

Familiarity with Design Concepts
The four interviewees communicated varying levels of familiarity with design concepts represented within the fabric collection that was shown. Interviewee three noted that a number of the design concepts shown were similar to those being worked on within his
company to develop new gift and flower wrap products. The interviewee was familiar with the technique of trapping bundles and ribbons of fibre between webs and creating bands of differing colour within a web. The other interviewee's were not familiar with the design concepts shown or the techniques used to achieve them.

8.4.6.2 Method

Response to Fabrics

Having viewed the fabrics, the interviewees were keen to know the specific production methods used in order to fully understand the fabrics from a manufacturing perspective. They were also keen to know what the fabrics might be used for because this would impact on the technical properties and therefore production parameters. In relation to this, it was noted that embedding materials between layers of fibre before the thermal bonding process appeared to have caused an interruption in the bonding of the fibre layers which could potentially result in a structurally unsound fabric.

In interview two, a fabric which had been creased using greaseproof paper in the pressing process to create surface texture was highlighted as being interesting and potentially commercial. It was suggested, before questions were asked in relation to the viability of manipulating their manufacturing processes to achieve such effects, that it could be relatively simple to incorporate such a technique using their main production line.

Design Capabilities

Although the manufacturers, had emphasised that 'design' from an aesthetic perspective was not their priority, they were willing to explore the potential opportunities within their production lines to manufacture fabrics for the design sector. The interviewees were asked about the 'design capabilities' within their particular production lines. Information regarding aspects of manufacture that impact on fabric design from an aesthetic perspective was sought. Aspects discussed included: fabric structure and weight range; surface and handle; range of fibres and use of colour; fabric finishing and; fabric size.

Fabric Structure, Weight and size

The core technologies used by each of the companies determined the specific nonwoven structure produced (see Table 4). Each of the companies was capable of producing a range of fabric weights from very sheer (15 – 30 gsm²) to heavy fabrics (up to 300 gsm²) alongside the ability to manipulate the surface quality and handle of the fabrics. Each company produced fabrics of a set width dependent upon the scale of their production. It was noted, however, that the fabric went on to be cut into smaller widths dependent on the application.
Surface and Handle
Each of the interviewees highlighted ways in which the surface quality and handle of their fabrics could be adapted in regard to tactile, visual or decorative qualities. Each of the company's manufacturing processes and parameters could be manipulated to some extent to determine the fabric handle. Companies two and four could further adapt the surface quality of the fabric by mechanically embossing decorative or functional three dimensional patterns into the fabric. Company two also highlighted the ability to create three dimensional surface textures by combining layers of web with different shrinkage rates.

All four of the companies interviewed had the capability of printing their fabrics for decorative effect and applying coatings to achieve different surface qualities. In addition to this, as highlighted previously, company one had the capability of altering the structure of their fabric to decorative effect by adding additional fibres and filaments between layers of web and creating decorative clusters of fibre.

Range of Fibres and Use of Colour
Each of the companies used a set range of two or three fibres. These fibres are selected on the basis that they give the optimum manufacturing results and the required fabric properties. Each of them highlighted, however, that in theory any fibre in the correct form, (filament or staple) could be used. It was highlighted that natural fibres are not usually used owing to the fact that they are not always uniform in terms of length and thickness which can result in inconsistent fabric properties. This would be unacceptable within technical market areas.

All four companies had the capability of producing coloured fabrics. This was achieved predominantly through dying fabrics after they had been constructed rather than by using coloured fibres. It was noted in interview four that coloured fibres are not used on the main production lines owing to the problems associated with cleaning machinery and undesirable effects produced when they find their way into other fabrics.

Finishing
Each company had the capability to print their nonwovens for either functional or decorative purposes. They also all had the capability (or potential) to emboss functional or decorative pattern onto their fabrics. Company two had facilities for hydro-entanglement which could be used to create three dimensional patterns within their fabrics. In regard to coatings, each company could apply a range of products to manipulate the surface quality and handle of their fabrics.
Transferability of Design Ideas

The researcher explained the production techniques that had been used to produce the fabrics to the interviewees. In discussing this and in response to specific questions a number of issues were raised in regard to the feasibility to replicate the ideas on larger production lines. Each company was open to discussing the feasibility of producing the designs on a larger scale but it was highlighted that the ideas would probably need to be 'diluted down' to make production viable and that elements of the techniques used may need to be eliminated. Key themes within the discussions included: the requirement to stop and start machinery during production; the ability to access webs in production in order to embed additional materials; the use of coloured and natural fibres; the incongruity between production scale and volume required and; the need for specifications.

Stopping and Starting Machinery for Design Intervention

The researcher explained that in order to embed additional materials and yarns into the fabrics the pilot scale production on which the fabrics had been produced was stopped and started at specific points on request. The interviewees from the second company highlighted that this would be practically very difficult and economically unproductive if using their production lines. It was highlighted that in their current practice, their main production line is only stopped at the end of a shift. A large amount of fabric is produced during a single shift and to stop production would considerably reduce the productivity of the line. Further to this it was noted that due to the size and scale of the line it would be difficult to stop the machine accurately to enable design interventions to be made owing to the fact that the line would not stop instantly on demand but would draw to a halt. It was suggest, however, that a 'mini-bulk' line could potentially be stopped every 20m with very careful planning to enable specific design placements to be achieved.

Accessing Webs for Design Intervention

It was noted by the researcher during the discussion that the embedded materials had been placed or scattered, by hand, between layers of web during production. As highlighted previously, company one had developed practices to enable flat materials to be placed between layers of web. Therefore the idea of developing fabrics with embedded fabrics, papers, threads and filaments was not problematic and was a real possibility in regard to their production technologies. Conversely, company four highlighted that, at their scale of production, all machinery was covered for health and safety reasons which would make it difficult (although not impossible) to intervene in the production process in this way. It was suggested by company two that similar effects to those achieved by embedding additional materials between layers could be achieved by printing similar motifs onto layers of individual
webs following production and then laminating the layers together. This was described as a 'dilution' of the original design concept to enable production on a large scale.

Using Colour and Natural Fibres

Although the companies interviewed produced coloured nonwovens, it was apparent that much of the colouration was achieved following fabric production rather than by using coloured fibres. It was noted in interview two that only white fibres were used on the company's main production line. In regard to the use of natural fibres and fibre blends, although each company indicated that, almost any fibre (if in the right form) could be used in production it was apparent that this was not part of their current practice due to issues relating to fibre uniformity. It was also noted that a large quantity of fibre would be needed to run the production line in a consistent manner owing to a need to run large scale lines prior to actual production to achieve fabric consistency. Interviewee three highlighted that to produce 100m of fabric a further 50m would be produced during the set up and stabilisation of the production line. This suggested that material costs would be high compared to the actual fabric output if using natural or luxury fibre for comparatively short runs.

Production Scale and Volume

The incongruity of production scale and the probable volumes required within the design sector were highlighted by the interviewees. It was suggested in interviews one and two that pilot scale lines or specialist commission processors would be more appropriate for small scale production than their main lines owing to the sheer amount of volume required to make running the main lines economically viable. It was suggested that any idea can be developed using pilot scale equipment. However, it was noted in interview two that the success of the fabrics in the market place would need to have been proven before the pilot line could be commercialised due to running costs. It was suggested that getting a major retailer on board with the product would aid this process.

Specifications

In order to translate the fabrics successfully in production, it was noted that accurate specifications in terms of fibre blend and required fabric weight would be needed. It was also suggested that melt temperatures and pressure levels for calendar bonding would be useful for accurate reproduction. This pointed to the values of developing accurate records of making during craft production on both hand or pilot scale production levels.
Collaboration

It was considered that it would be beneficial to gain an indication of the manufacturers' openness to working with designers and so relevant questions were asked to elicit this information. Each of the companies had collaborated previously with designers through providing samples of their current fabric ranges. However, none of them had collaborated with designers on the production of new nonwoven fabrics. Although enthusiastic about the potential for new products and applications, both company one and two saw such collaboration as economically unviable unless there were proven records of the fabric's commercial success. Companies three and four, in theory, willing to collaborate in the production and development of the fabrics using their manufacturing lines within the context of research.

8.5 Summary

This chapter has outlined the methods used to conduct focus groups and interviews with textiles and product design professionals and nonwoven manufacturers as a means of: generating external evaluation on the aesthetic qualities of the fabrics that had been developed within the practical stages of the research; establishing the suitability of the fabrics for various and specific end uses and markets and; gaining an indication of manufacturing opportunities and limitations to manufacture the fabrics produced within the context of industrial nonwoven production. The analysis can be summarised under the following headings; aesthetic; use; associations and value; commercial viability and; manufacturing possibilities.

8.5.1 Aesthetic

In summary the interviews and focus groups revealed that a number of the fabrics produced had aesthetic appeal, particularly, in regard to their tactile qualities and the way in which they interacted with light. Heavier fabrics were perceived as most suitable for high-end markets and it was noted that the effects achieved by embedding materials within the fabric structure created unique designs. The effects achieved by devoré in regard to producing translucent pattern were also highlighted as unique qualities. This underlined the importance of intervention and finishing techniques in producing high value nonwovens.

8.5.2 Use

From an aesthetic perspective the fabrics were seen as suitable for use within lighting and wall-covering. However, some concerns were raised about the suitability of the fabrics from a functional perspective due to their perceived low strength. However, it was noted that, providing the fabrics could be suitably backed and protective finishes applied, they could be suitably used within high-end markets.
8.5.3 Associations and Value

The results revealed that the fabrics prompted associations with a range of existing textile products. These included associations with conventional felts, papers and plastics but it was noted that fabrics which had a ‘less obvious structure’ began to move away from felt and began to take on a unique quality. Associations with felt prompted a sense of familiarity and comfort which the participants found appealing. However, some of the fabrics were connected with conventional nonwoven products such as cleaning cloths. It was noted that such associations devalued the fabrics in question.

In regard to value it was noted that the heavy fabrics in particular would be suitable for high-end interior markets. The perception of nonwovens as industrial fabrics and thus their lower perceived value in the traditional sense was highlighted and noted as a potential barrier in regard to commercial viability. The notion of traditional material value was emphasised within the discussions and it was suggested that the incorporation of natural fibres into nonwovens may, if recognisable, imbue them with a sense of value.

8.5.4 Commercial Viability

The difference between the volumes required for high-end interior markets and the volumes usually produced within nonwovens manufacture was perceived as a potential barrier in regard to the commercial viability of the fabrics. It was noted that producing small runs would be expensive and may not be balanced by customer demand.

8.5.5 Manufacturing Possibilities

The interviews with nonwoven manufacturers highlighted that to produce the fabrics on a large scale production level the fabric design would have to be adapted and essentially ‘diluted’. Although a number of the design techniques employed on a pilot scale level were perceived as theoretically viable in terms of larger scale production, from an economic perspective it was perceived that producing the fabrics would be unproductive. It was suggested that for a manufacturer to take on these ideas using their main or ‘mini-bulk’ lines the fabrics would first need to prove their success in the market place.
9.1 Introduction

This thesis has established that designers and makers working within fashion, textile and interior design have for some time worked with nonwoven fabrics and production technologies to achieve particular aesthetic aims. There appears, however, to be little fluidity between craft and industrial production contexts within this sphere and much of the work conducted by designers has centred on the use of needle-punching. Because of this, the design potential of nonwoven technologies has not been fully realized. To further explore the design potential of nonwoven technologies the work presented in this thesis was based around the following suggestion;

*By pursuing a mode of design practice that i) explores the development of nonwoven fabrics for design purposes through hands-on interaction with nonwoven technologies (in other words by pursuing a craft approach to design) and ii) considers the practical and contextual limitations of industrial production, new fabrics can be achieved and links between designers and industry can be built, thus expanding the application of nonwoven technologies within textile design.*

In order to investigate this, the following research questions were asked;

1. What aspects of industrial nonwoven technologies can be appropriated using hand-based textile processes?

2. What aspects of pilot scale carding and thermal bonding processes that utilise heat and pressure can be manipulated for aesthetic purposes?

3. How can printing, embossing and laser cutting and marking processes be used to add further aesthetic value to the fabrics produced?

4. Are the fabrics produced suitable for high-end markets, and in particular the interior decorator market?

5. What opportunities and limitations exist in regard to producing such fabrics within the context of the nonwovens industry?

To answer these questions practice based research was carried out. This chapter summarizes the work conducted and the research findings in relation to each of the above questions and within the wider context of current knowledge. In doing so, attention is drawn to the aspects of the work that contribute to new knowledge. Areas for future work are also identified.
9.2 Summary of Work Conducted and Research Findings

A summary of the work conducted and the research findings in relation to each of the research questions is given below.

9.2.1 What Aspects of Industrial Nonwoven Technologies can be Appropriated Using Hand-Based Textile Processes?

As explored in Chapter 2, theory relating to textile and product design highlights the importance of craft knowledge to research and development within industry (Harrod, 1999, Dormer, 1997, Yair, 2001, Roet, 2003). Craft knowledge has been described as ‘know how or hands on knowledge’ and as ‘an understanding or feel for materials’ (Yair, 2001). It has been suggested that such knowledge is valued because of the quality of the objects that it informs (Pye 1958, Rees, 1997) and past research confirms that it is also valued in regard to product development within industry (Yair, 2001).

The first research question was asked to enable the researcher to develop a hands-on understanding of nonwoven technologies, to document the processes used and the results achieved, and, to begin to explore the design potential of the processes under investigation.

9.2.1.1 Work Conducted

This question was initially explored within Chapter 2 by mapping industrial nonwoven technologies and hand-based textile processes. Based on this, a series of practical investigations into hand-based methods of nonwoven production were conducted.

It was established in Chapter 2 that needle-punching has been the most explored nonwoven production process by designers and that much of the work has focused on the effects of fibre transfer and the use of needle-punching as an appliqué like technique (Marsden, 1977 Bartlett, 1997, Appleton, 2004 and Tait, 2004). The practical investigations conducted, therefore, focused on hand-based methods of web forming, chemical bonding and thermal bonding using workshop based equipment.

9.2.1.2 Findings

Web Formation and Fibre Preparation

A drum card was used to prepare fibres and form webs. A variety of fibre types were processed to produce a range of webs. This aspect of the investigation enabled an understanding of how each fibre responded to the carding process to be gained and for the visual and tactile qualities of the resulting webs to be documented. Various visual and tactile
qualities were achievable and were determined by the fibres used. The webs produced, however, generally had a textured and somewhat uneven quality.

**Chemical Bonding**

Traditional screen printing techniques were drawn upon to establish a method of chemically bonding the webs by hand. The methods used were initially problematic due to the fragility of the webs prior to printing. Through applying starch prior to printing and by incorporating a protective layer of net between web and screen a workable method was, however, established. Only light-weight webs were successfully bonded as the binder solution did not penetrate beyond one or two individual fibre layers. Spraying binder solution was also explored as a means of chemically bonding webs by hand. The visual and tactile qualities of the fabrics produced using both methods were to a large extent determined by the quality of the original web but were also effected by the type and quantity of the binder.

As highlighted in Chapter 2, chemical bonding methods, such as screen printing and spraying, are well established within the nonwovens industry. Whilst the research presented in this thesis has drawn on established knowledge to achieve the results outlined, hand-based screen printing and spraying methods have not until this point been documented as hand-based methods of bonding drum-carded webs to produce nonwovens.

**Thermal Bonding**

Industrial methods of thermal bonding using binder fibres, heat and pressure were appropriated on a studio based level using a heat transfer press. Binder fibres were blended with main fibres by using hand carding processes. Webs were produced using drum carding and were bonded by applying heat and pressure using a heat transfer press. This method proved a consistent means of creating nonwovens using a range of fibre types and blends. As established within industrial production, the visual and tactile qualities of the fabrics produced were impacted upon by the quantity of binder fibre in the web and the temperature and dwell time at which the webs were bonded.

Owing to the consistency of this method and the superior quality of the fabrics produced, this process was taken forward into a period of design development.

**Design Potential**

Traditional felt making techniques were drawn upon to explore the design possibilities of drum carding and thermal bonding using a heat transfer press. The potential to exploit the textural qualities of various fibres through fibre selection was identified as were the opportunities to
create visual depth, pattern and structure by incorporating extra fibres and yarns at the web formation stage of production. The ability to develop composition by controlling the placement fibres within the web was also confirmed.

9.2.2 What Aspects of Pilot Scale Carding, Needle-punching and Thermal Bonding Production Processes can be Manipulated for Aesthetic Purposes?

Peter Dormer’s discussion relating to innovation within Woven Textiles was highlighted in Chapter 2. Dormer (1997, p.168) suggested that the innovation achieved within woven textiles is due to the continuity and fluidity that exists between craft and industrial production. He noted that this fluidity enables samples produced on a hand-based level to be translated for industrial production without fuss. In relation to this, attention was drawn in Chapter 2 to Lenor Larsen’s notion of ‘Class Production’. Larsen’s (1985) notion proposes a mode of textile production that sits between one-off and mass production and in which design is central to production. To begin to explore the continuity between hand-based and industrial production within the area of nonwovens and to enable innovative and ‘class’ fabrics to be produced, thus expanding the application of nonwoven technologies within textile design, the second research question was asked.

9.2.2.1 Work Conducted

To investigate this question, the researcher pursued collaborations with nonwoven manufacturers and research groups who operate pilot scale equipment. Within the nonwovens industry, research and development work is often carried out using pilot scale industrial equipment. Pilot scale equipment mimics large scale production equipment but enables smaller runs of fabric to be produced for experimental purposes.

The findings of the hand-based design development work relate to several means of manipulating nonwoven production processes that have already been identified within past research. For example the use of different fibre types, controlling fibre transfer in needle-punching and needling fibres, fabrics and yarns to the surface of fibre webs (Marsden, 1977 Bartlett, 1997, Appleton, 2004 and Tait 2004). These methods, however, are reliant on the needle-punching process. In order to build on this knowledge the work conducted within this aspect of the research focused on manipulating carding and thermal bonding methods that utilize heat and pressure rather than on needle-punching. Since carding can be followed by any number of bonding processes it was felt that the results achieved would have a wide application within industry. Owing to issues relating to the transportation of fibre webs to appropriate bonding equipment, however, needle-punching was incorporated into the sampling process as a means of tacking webs before thermal bonding. This gave the webs enough structural integrity to be handled with minimum damage.
Chapter 9 Conclusions and Further Work

The fabrics produced during the hand-based design development work formed a starting point for this stage of the research. The pilot scale processes employed were manipulated to enable the ideas embodied within the hand produced samples to be reproduced. As the work progressed the impact of different production parameters on the quality of the resulting fabrics were observed from a subjective perspective. As discussed in Chapter 5, literature on nonwovens documents the impact of different carding, needling, and calendaring parameters on the properties and qualities of the resulting fabrics for example, handle, drape, surface quality and strength. Within this research it became apparent that embedding various materials within webs changed the way in which they reacted to calendaring and heat pressing. The effect of the quantity of binder fibre within the webs, the extent of needling prior to thermal bonding and the heat, speed and pressure at which fabrics were calendared or heat pressed on the resulting fabrics was, therefore, observed.

On completion of this stage of work and having begun to explore ways of further designing the fabrics using printing, embossing and laser processes, design collections were produced, as discussed in Chapter 7.

9.2.2.2 Findings

Limitations and Opportunities of Pilot Scale Machinery

The work conducted in Chapter 5 demonstrated that nonwoven designs produced using hand-based methods could be translated using pilot scale equipment. However the aesthetic qualities of the fabrics produced were quite different. The fabrics produced, using the pilot scale equipment, were much smoother and more uniform in terms of surface quality and structure than those produced by hand. In terms of fluidity between production contexts, although the hand-made fabrics provided a useful starting point, it was clear that the use of pilot scale machinery was an essential intermediary stage between hand-based and industrial production. The pilot machinery impacted upon the extent to which the design techniques could be implemented as well as the quality of the resulting fabrics and it was evident that each pilot line presented different opportunities and limitations dependent upon the specificities of each piece of machinery and at each stage of production.

At the web formation stage, the scale of the carding and the layering mechanisms impacted upon the extent to which different fibre types and additional materials could be purposefully positioned within the web. In terms of design, these factors determined the compositional possibilities and the types of materials that could be embedded between fibre layers. The scale of machinery also impacted upon the extent of hand-intervention that was appropriate. Of the systems used, the horizontal cross-lapping line at the CMRI proved to be the most versatile system.
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The scale of the CMRI line meant that the researcher/designer could intervene by hand as carded webs travelled to the cross-lapper enabling additional materials to be placed within the webs. This also meant that it was more feasible to incorporate yarns and pre-made warps into the fabrics. Further to this, the researchers close physical proximity with the process enabled any problems at the layering stage to be identified and rectified which enabled a wider range of fabrics to be realised successfully.

The size of fabric to be produced also impacted on the level of control in terms of design. During the sampling process the size of web was kept constant by not activating the output belts on the cross lappers. This enabled a greater level of control over composition and enabled different fibres to be layered in a specific sequence. To produce lengths of fabric the cross-lapping systems had to be activated which made it more difficult to control composition precisely and to layer different fibres in a controlled sequence. In large scale industrial production, however, multiple carding lines could be used to overcome this problem.

The speed of production was one of the most impacting aspects of developing design using pilot scale machinery. The production process was much quicker than hand-based sampling and once started it was only a matter of minutes until a web had been produced. This placed a great importance on planning prior to production as there was no real time to reflect and re-work fabrics during the making process. It was possible, however, to stop and start the CMRI line during production, which although potentially detrimental to the quality of the resulting fabric, provided more time for design decisions to be implemented during production.

Production Parameters

As identified in literature on nonwovens, the work confirmed from a subjective perspective that the greater the quantity of binder fibre in the web the stiffer, smoother and stronger the resulting fabric. It was also confirmed that these qualities increase as the heat pressure applied to the webs increases. Further observations relating specifically to webs with materials embedded within them were made. For example, when calendaring webs with relatively bulky materials embedded within them the webs tended to distort. If the gap between the calendar rollers could be manipulated then this effect could be controlled and webs with flatter fibres in them, and those that had been more heavily needled were more successfully calendared. A greater diversity of materials could be successfully processed using the heat press and the results were more consistent.

Working Context and Sampling Procedure

As noted previously, the opportunities and limitations of the pilot scale machinery employed were specific to each working situation. The opportunities and limitations were not only
determined by the specifics of the machinery, but also by the willingness of the technician to be experimental, and the working relationship between the technician and the researcher. The machinery was operated by a technician and any adaptations to the usual procedure had to be negotiated which meant that constant communication between technician and researcher was essential in attaining the desired results. The work was therefore impacted by both the researcher’s and technician’s imagination and expertise in regard to machine operations. This suggests that the results of this research are largely context specific.

The design development work discussed in Chapter 7 was conducted at the CMRI owing to the scale and versatility of the machinery. The availability of a number of short periods on the line also meant that the work could be effectively planned. In terms of a sampling procedure for this stage of the work, based on the results presented in Chapter 5, it was decided that carding, light needling and heat pressing proved to be the most effective and consistent way of making fabrics that incorporated different design elements. The design focus remained on the web formation stage of production.

**Design Opportunities**

Embedding fabrics, fibres and yarns between layers of web was identified within this research as one of the main ways of designing with carding and layering technologies. The methods developed and the observations made in regard to this form an original contribution to knowledge within the sphere of nonwovens. The methods used were unique to those previously attained in previous research as they are employed at the web forming rather than web bonding stage of nonwoven construction. The webs produced could, in theory, be bonded using any web bonding technology. The fabric designs produced, therefore, have a wider relevance to the nonwovens industry.

The process of embedding fabrics, fibres and yarns between layers of web enabled colour, simple motifs and different textural elements to be integrated into the nonwoven structure. A sense of visual depth was achieved and the addition of yarns enabled an impression of structure to be realized within the designs. A number of considerations in regard to the incorporation of this technique into small scale production runs were made. It was noted that the technique relied heavily on hand intervention and the careful monitoring of production. Dependent on the type and quantity of material that is to be embedded, production had to be stopped and started to enable the required quality of fabric to be achieved. This process relied on constant communication between the production technician and the researcher. The design limitations related predominantly to the compositional effects that are achievable.

Further ways to control the carding, layering and bonding systems for design purposes including; the ability to build up individual layers of different fibre types (and colour) within one
web; controlling fabric weight; creating graduated effects across the surface of the fabric in terms of colour; texture and tone and adapting fibre blends were identified. When the resulting fabrics were further processed using printing, embossing and laser techniques a number of unique and original fabrics were realised.

9.2.3 How can Printing, Embossing, Laser Cutting and Marking Processes be used to Add Further Aesthetic Value to the Fabrics Produced?
As highlighted in Chapter 2, printing, embossing and laser processes are routinely used within the nonwovens industry for both decorative and functional purposes. In regard to the use of nonwovens within design, it has been suggested that the relative low cost of nonwovens often affords designers the opportunity to employ expensive finishing processes to achieve innovative effects (Braddock, 2005). Within this work the researcher was in a unique position in which she was able to adapt the finishing processes specifically for the fabrics that had been produced and conversely to design the fabrics specifically for certain finishing processes.

9.2.3.1 Work Conducted
During the initial sampling work, flocking, foiling, devoré and printing processes were tested. Embossing using various plates and presses was explored and laser cutting and marking systems were experimented with. Further work was conducted, as described in Chapter 6, to observe the impact of various fabric construction parameters on the quality of the printing, embossing and laser marking results achieved. A set of viscose and ramie samples were produced specifically for use in this stage of the work. Different fibre blends, needling and thermal bonding parameters were used within the sample set in order to observe the impact of each on the success of each process. The parameters of each finishing process were also controlled and adapted to enable the best sampling parameters to be identified.

In order to further develop the design potential of the fabrics produced, the possibilities of using printing, embossing, laser cutting and marking processes on them was explored using various patterns and colour schemes. The results of this work informed the development of the design collections which are discussed in Chapter 7.

9.2.3.2 Findings
The work conducted confirmed that printing, laser marking and cutting could be successfully applied to the nonwovens developed within the research (i.e. carded, needled and heat pressed nonwovens made from a range of fibre types blended with a thermoplastic binder fibre).
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The investigations confirmed that the fibre type, blend and fabric construction parameters do impact on the results achieved.

Flocking and Foiling

In regard to flocking and foiling, it was noted that the quantity of binder fibre within the fabric affected the quality of flock or foil achieved. The greater the quantity of binder fibre the less 'clean' the resulting flocked or foiled print.

Devoré

The devoré process enabled unique surface effects to be achieved. The process was initially problematic, however, particularly in regard to lighter weight webs. The high water flow and rubbing action used in the washing-off process proved too aggressive for the fabrics causing them to become degraded. The process was adapted, therefore, to incorporate the use of a low pressure hose and a gentle rubbing action to wash the fabrics as they lay flat in a resin bath. This process was successful and enabled the quality and integrity of the original fabrics to be retained. This aspect of the work showed the potential for much design development and forms the basis of an original contribution to knowledge within the research.

The further investigations into the devoré process, described in Chapter 6, indicated that the extent of needling and thermal bonding had a subtle effect on the quality of devoré print achieved. The most impacting factor in regard to the quality achieved was the fibre blend employed within the fabric. The greater the ratio of cellulose based fibre to binder fibre (and other fibres within the blend) the more dramatic the devoré effect.

Laser Marking

Due to the environmental implications of the devoré process, laser marking was explored as an alternative means of achieving a 'burn-out' process. Two laser marking techniques, which are as yet un-explored within the current body of knowledge in regard to nonwovens, were trialled and showed potential for design development. Using a raster marking process Bitmap images were 'rendered' onto the surface of the fabrics. The image was essentially burnt into the fabric. The burnt fibres could be removed using the same washing off process as adapted for devoré printing. The success of removing the burnt fibres was, however, dependant on the fibre type and blend. Some fibres could not be dislodged from the fabric structure which resulted in a singed affect on the fabric surface. The second process employed Vector based designs. The outlines of the motifs were marked onto the fabric surface and the top layers of fibre within the motif area were then removed by hand from the fabric surface. Although the process was time consuming and somewhat inconsistent it did
not require a washing off process and left no evidence of burning on the fabric surface. Both processes, when applied to the fabrics made within this research, formed unique and original surface effects.

**Embossing**
A heat transfer press was successfully used within this research to emboss nonwovens using laser cut steel plates enabling relief pattern to be achieved. Embossed steel rollers are routinely used within the nonwovens industry for this purpose, however, owing to the high costs of producing engraved rollers the process employed within this research demonstrates a relatively economical method of embossing nonwovens which is more appropriate for use in the high-end design sector where new patterns are required on a continual basis.

**New Design Opportunities**
Owing to the approach taken within this work, the researcher/designer was in a unique position of being able to design both the fabric construction and the surface design aspects of nonwovens. When the fabrics were constructed specifically for further processing (surface design) some innovative and original design potential was identified.

**Revealing Embedded Elements**
The devoré and laser marking techniques employed in conjunction with surface patterns enabled the embedded elements within the nonwovens to be highlighted and/or revealed within the fabric designs. Contrasting visual and textural qualities were achieved and specific areas of pattern were emphasized. The effectiveness of such designs relied on embedding the additional materials at an appropriate depth within the fibre webs, using an appropriate blend of cellulose/non-cellulose base fibres and binder fibre and selecting contrasting fibre layers and/or embedded materials appropriately. The quality of fabric achieved was further reliant on hand based finishing processes. The adaptation of the devoré process for nonwovens and its use on specifically designed nonwovens further builds on the contribution to knowledge made within this research and the establishment of an original body of design work. Similarly the laser processes used in conjunction with specific nonwovens constructions, although not as resolved as the devoré process, shows potential for a new aesthetic.

**Creating Contrasting Surface Texture**
The devoré and laser marking techniques established enabled contrasting layers of fibres to be revealed, which created contrasting surface texture and colour within the designs. To
successfully achieve these effects it was noted that the correct sequence of layers within the webs was essential and that the fibre blend used for each layer needed to be carefully considered in regard to cellulosic/non-cellulosic fibres. The fabrics produced using this approach form a significant contribution to the original body of designs presented in this thesis.

**Lightweight Fabrics**

The ability to create lightweight, translucent fabrics using nonwoven technology was exploited by devoré printing and laser cutting multiple webs and laminating them using heat and pressure. The fabrics produced were particularly effective when viewed in front of a light source. The surface patterns employed took on an ethereal and delicate look that was unlike that producible using conventional textile structures. The fabrics achieved, therefore, formed a significant aspect of the body of designs presented.

**Context Specificity of Research Results**

Whilst the results achieved in response to this question have been systematically found and analyzed it is acknowledged that the researcher/designer's past experience, approach to design and aesthetic sensibility and personality have impacted significantly on the design development aspect of the research. Whilst it is hoped that had another designer have embarked upon the work, the essence of the results would have been similar, but it is acknowledged that the resulting fabrics might have been quite different. It is therefore important to note that the results are, in this sense, context specific.

9.2.4 Are the Fabrics Produced Suitable for High-End Markets, and in Particular Interior Products?

In Chapter 2 a number of current nonwoven products that currently function at the high-end of the interiors market were highlighted (Stereo 2004, Zimmer and Rhode, 2005). These products, often designed as wall-coverings, function more like papers than fabrics and provide a modern technical aesthetic to co-ordinate with more traditional materials. Since the beginning of this research further nonwovens have appeared within this market. For example, Mantero (2007) have launched a nonwoven fabric called 'Re-Silk'. The fabric is made from 50% recycled wool and 50% recycled silk and appears to be constructed using the needle-punch process. The fabric itself is a plain nonwoven structure (in other words no 'design' has been incorporated during it's construction). It is sold on the basis of its quality and ecologically sound fibres and the ease with which it can be embossed, printed and cut. Such developments confirm that the study and further development of nonwovens for high-end markets presented in this thesis is timely and relevant. In order to assess the suitability
of the fabrics produced within this research for high-end markets a series of focus groups and interviews, as presented in Chapter 8, were conducted.

9.2.4.1 Work Conducted
A pilot set of focus groups with textile and product design undergraduates and a further set of focus groups with textile design professionals, academics and postgraduate students were conducted. The purpose of the groups was to gain external review of the aesthetic qualities of the fabrics produced, to gauge opinion on suitable end uses for the fabrics and their appropriateness for specific markets. The results of these groups suggested that the fabrics would be most suitable for lighting, window treatments and wall-covering. Based on the results of the focus groups, four interviews with product designers working within the high end of the interiors market were conducted. Victor Papanek’s (1985) Function Complex was used as a framework for analysis.

9.2.4.2 Findings
The focus group discussions highlighted the aesthetic appeal of the fabrics as well as pointing to some less desirable aspects of them. The identification, by participants, of associations that the fabrics prompted with products, emotions and environments formed a significant element of this aspect of the discussions. These associations impacted upon how the participants could envisage the fabrics being used and where they felt the fabrics would fit within current markets. The findings of both the focus groups and interviews are summarised below in relation to various aesthetic and design considerations.

**Weight and Handle**
The participants’ initial responses to the fabrics indicated that the fabrics had tactile appeal. The variation in weight and handle of fabrics within the collections, and contrast within the surface qualities of individual fabrics were seen as positive aspects of the fabrics. Such observations suggested that by using the processes and procedures presented in this study, it is possible to realize the ‘deliberate intentions about (very) small details and qualities of surface’ that Pye (1958, p.57) associated with the prized qualities of handwork and that potentially lead to greater aesthetic value.

Fabrics that had a softer handle were perceived as more appealing than those with a relatively hard handle. This was interesting to note as most of the nonwovens that currently function within the high-end interiors market have a hard synthetic quality.
Although the interaction of different fibres and materials created contrast within the surfaces of individual fabrics, variation between the surface qualities of fabrics within the collection was perceived as minimal. Most of the fabrics were thought to have a smooth, felted and flat surface quality. Owing to this, it was suggested that the fabrics would be suitable for various two dimensional surface coverings such as wall-coverings, flooring and screening.

The weight and handle of the fabrics impacted upon the associations that they prompted. For example, lighter stiffer fabrics were associated with nonwoven interlinings and paper. In regard to certain fabrics this led to a lower perceived value. Heavier, softer fabrics were associated more with felt which, on a number of occasions, prompted emotional associations such as warmth and comfort. This further confirmed the aesthetic appeal of these fabrics from a tactile perspective.

**Fibre Type**

The visual and tactile difference created by using different fibre types within the fabrics was identified but it was noted, however, that these differences were not as prominent as those evident in traditional fabric structures. It was suggested that the use of traditionally valued fibres such as cotton and silk affected the actual and the perceived value of the fabrics. It was suggested that the fabrics that contained such fibres would be more appropriate for higher end markets.

The interviews revealed that nonwovens have been used by some high-end interior design companies as contemporary co-ordinates within collections. Although the nonwovens in question did function in this way, it was interesting to note that they reportedly had less appeal than traditional fabrics and were, therefore (at the time of interview), in less demand than traditional fabrics. It was suggested that consumers do not attribute the same value to nonwovens that they would to traditional cotton and silk fabrics partly because of the unfamiliarity of nonwovens. It was clear, however, that industrially produced nonwovens hold contemporary appeal within niche markets because of their technical qualities.

**Fabric Structure and Construction**

In relation to the fabric structure, and more specifically the extent of fibre entanglement, it was suggested that some of the fabrics were more ‘obviously constructed’ than others. Where the fabrics were perceived as ‘less structured’ it was suggested that they took on a quality distinct to paper and felt.

Also related to fabric structure was the issue of fabric performance and durability. The results indicated that the fabrics presented were, on the whole, perceived as relatively delicate.
Concerns were expressed about their ability to withstand certain product manufacturing processes and their subsequent durability in use. It was suggested, however, that from a performance perspective the fabrics would be suitable for use in products that withstand low levels of physical wear and tear such as lighting and wall coverings.

In relation to fabric construction, the results indicated a considerable level of interest from participants in the nonwoven production process. This related to Rees' (1997) discussion about the level of consumer ‘accessibility’ to designed objects and in particular her suggestion that it is dependent to some extent on the consumer’s understanding of the processes used to make the object. The focus groups and interview discussions suggested that a greater level of understanding enables a more personal connection between consumer and object. As a point of further investigation it would be interesting to question whether or not the fabrics in question revealed the physical input of a creative individual alongside industrialized production. As Rees (1997) suggests, this would impact upon the consumers perception of the fabric as being either the product of an individual's creative practice or a product of mass manufacture which, would in turn impact upon the perceived value of the fabric. Further research into such theories in regard to nonwovens would prove beneficial in the development of fabrics for design-led markets.

Interaction with Light
The interaction of the fabrics with light was suggested as one the unique appealing factors of the collections. The way in which fabrics with additional materials embedded within them interacted with light was described as ‘transformative’. Owing to this it was suggested that many of the fabrics would be suitable for use in lighting and window treatments. The visual appeal of the fabrics when filtering light was confirmed by product designers in regard to lighting design. In particular, the way in which certain design elements were revealed through the introduction of light.

The ability to build up distinct fabric layers was noted as a successful means of exploiting the way in which the fabrics interacted with light but it was highlighted that pattern and colour combinations needed further consideration.

Pattern and Colour
In regard to the application of pattern to the fabrics, it was noted that the ‘fading’ effect achieved by devoré was particularly successful. The effects achieved through embossing were perceived as having potential but it was suggested that further work was needed to create a more definitive three-dimensional surface.
In regard to the success of using decorative finishing processes to add aesthetic value to the fabrics, notions of complexity/simplicity and overstatement/understatement were important aspects of the discussions. It was suggested that within the collections too many techniques had been combined resulting in overly complex designs and that the results were more successful when decorative finishing processes had been employed in a less explicit manner. Conversely, it was noted by some participants that combining a variety of processes gave the fabrics a sense of the hand-made and subsequent value. Some of the effects achieved were noted as being overstated and whilst it was acknowledged that there was a place for such fabrics within commercial textile collections it was generally agreed that the fabrics that were perceived as understated were more appealing.

Pattern and colour had a significant impact upon the associations that the fabrics prompted, the value that was attributed to them and their perceived market level. For example, when hand drawn floral motifs had been used within the designs, links with Japanese prints and hand made papers were made, and the use of lace prompted historic connections, both which prompted higher perceived value. Conversely the use of more stylized floral motifs was perceived as creating cheaper looking fabrics.

The results of the focus groups indicated that colour was one of the factors that informed the associations that were made with other products and in particular with industrial nonwovens. Strong blues, reds and pinks within the collections were linked to cleaning cloths and other functional products that are often made from nonwovens. The use of un-dyed fibres and soft tonal ranges within designs were perceived as being more sophisticated and therefore more relevant to the higher end of the market.

**Embedded Materials**

The perception of the fabrics in which additional material had been embedded related to the quality and nature of the embedded materials as well as the base fabric. This related not only to the formal qualities of the resulting fabrics but also to the associations that they prompted, and the value that was attributed to them and perceived market level. For example the inclusion of dried flowers within the fabrics prompted associations with handmade papers and cheap products such as paper lanterns. The inclusion of shiny metallic threads was perceived by some participants as tacky but by others as adding a superficial sense of value.

In regard to the impact of the embedded materials on the formal qualities of the fabrics, the embedded materials were thought to draw the viewer into the design and the inclusion of yarn in particular was perceived as bringing a greater sense of structure to the fabrics. The quality of visual depth created by the embedded materials was suggested as being of potential
interest within the high-end wall covering market. Although this quality prompted associations with Japanese paper screens, it was considered as a unique and appealing quality.

In summary the results of the focus groups and interviews revealed that some of the fabrics produced are suitable for high-end interior products. It is clear that certain aspects of the fabrics presented are more desirable than others within this context. Alongside the intrinsic qualities of the fabrics themselves, the use of colour, pattern and the quality of the materials used impact upon how appropriate the fabrics are for high-end markets. The qualitative nature of the analysis made, provides a new perspective on the design value of nonwovens and the key discussion points identify areas for beneficial further study.

**Subjectivity and Limitations of the Results**

It is acknowledged that although the results provide a new perspective on the design value of nonwovens they are context specific and relate directly to the researchers and the participants' perspectives on design and the cultural context in which the research was conducted.

9.2.5 What Opportunities and Limitations Exist for Producing such Fabrics within the Context of the Nonwovens Industry?

The theoretical framework established in Chapter 2 documented past research into the nature of craft/industry relationships in regard to new product development, much of which related to live commercial projects (Yair, 2001, Weisbrod, 2003, 1998, Cummings 1984, Harrod 1999, Roet 2003). A number of key factors that are considered crucial in establishing successful links between craft and industry were highlighted. Four of these factors were outlined in Chapter 2 and include; the notion of contextual fit, the need for mutual benefit; an approach to design from the craftsperson/designer that incorporates sensitivity to industrial manufacture and; the existence of a shared language between craftsperson and industry that includes but goes beyond technical terminology. With these factors in mind the following work was conducted to explore the practical and contextual limitations of industrial nonwovens production in regard to design.

9.2.5.1 Work Conducted

Chapter 7 documented aspects of pilot scale carding, needle-punching, and thermal bonding processes, which could be manipulated for design purposes. To begin to establish the limitations of commercial production, the analysis within Chapter 7 included suggested points for considerations if producing small runs of specific designs within a pilot scale production context. Considerations that would need to be taken to effectively translate the designs.
produced within a large scale commercial manufacturing context were explored through a series of interviews and discussions with nonwoven manufacturers, as documented in Chapter 8. Further to this, collaborative work between the researcher/designer and an established nonwovens manufacturer was pursued and documented.

9.2.5.2 Findings
The findings of the interviews were organized into two categories. The first related to the feasibility of translating the fabric design presented in this thesis for industrial manufacture. The second related to the current capabilities of each manufacturer in regard to designing nonwovens.

Translation of Ideas for Industrial Manufacture

Embedding Fabrics, Fibres and Yarns
During the design development stage of the research a number of considerations in regard to incorporating the technique of embedding fabrics, fibre and yarns between layers of web for pilot scale production runs were made. It was noted that the technique relied heavily on hand intervention and the careful monitoring of production. Dependent on the type and quantity of material that was to be embedded, production had to be stopped and started at specific points to enable the required quality of fabric to be achieved. This process relied on constant communication between the production technician and the researcher/designer.

Some of the fabrics produced using this technique were presented to the nonwoven manufacturers who had agreed to participate in the research. During the interview discussions it was suggested that on a full scale production line this technique, as it stood, would be difficult to implement from a practical perspective and would also be economically unproductive. It was highlighted that in industrial nonwoven manufacturing, it is often the case that main production lines are only stopped at the end of a shift due to the time involved in setting them up and to stop the lines between shifts would considerably slow down production. Further to this it was noted that due to the size and scale of the lines it would be difficult to stop the lines accurately to enable design interventions to be made. The line would not stop instantly on demand, but would rather draw to a halt. It was suggested however, that what was termed a ‘mini-bulk’ line could potentially be stopped every 20m with very careful planning to enable specific design placements to be achieved. In regard to design possibilities, this suggested that if designing nonwovens for this scale of production, there would be limitations in regard to repeat size and design scale. It may well afford the possibility for unique large scale design.
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During the design development work, additional materials had been placed or scattered by hand at the web formation stage of nonwoven production. Whilst this notion was familiar to the company who worked with spunlaid web formation techniques, it was not a familiar concept the companies working with carding technologies. The later companies highlighted the requirement that their machinery be enclosed for safety purposes, therefore making it impossible to intervene by hand in the production process in this way. It was suggested, however, that specially designed scattering devices could be employed. Further to this, one company recommended that the designs would need to be 'diluted' for production and that similar effects could be achieved through printing layers of individual web following production and then laminating them together.

Creating and Revealing Contrasting Fibre Layers

The ability to create webs with layers of different fibre types that are positioned to enable textured surface effects to be achieved through devoré printing and laser marking was one of the central design themes explored within the research. To successfully achieve these effects it was noted that the correct fibre blend within each layer and the correct sequence of these blends within the web was required. In regard to pilot scale production it was noted that only small samples could be produced using this technique. In order to produce fabric lengths it was necessary to create individual fibre webs and layer them by hand to produce the final web. Again, this process relied on constant communication between the production technician and the designer/researcher.

In regard to larger scale production, it was suggested that several carding lines could be used in combination to achieve the desired sequence of fibre layers within the webs.

Specifications

To produce the fabrics successfully using commercialized pilot or commission lines, it was noted that accurate specifications in terms of fibre blend and weight would be beneficial. It was also suggested that melt temperatures and pressure levels for calendar bonding would be useful for accurate reproduction. The adaptation of production to achieve particular effects would, as noted above, have to be negotiated with production staff. This relates to Yair's (2001) identification of the need for a shared language between researcher/designer and manufacturer that includes technical language but also the ability to communicate in a verbal, visual and bodily manner to enable ideas to be successfully communicated and realized. It is suggested that the requirement for close communication between designer/researcher within the mode of practice established within this research, enabled such a language to be developed.
Company Design Capabilities in relation to Fabric Designs

Finishing

Printing, embossing and laser techniques were central to the way in which nonwoven designs had been developed within the research. The successful application of these techniques, particularly devoré and laser marking, relied on careful processing to achieve optimum results. This was noted as the main consideration in regard to small scale production. In order to assess the appropriateness of industrial scale finishing techniques to achieve the desired effects, further research needs to be conducted.

Each of the companies interviewed had the capability to print their nonwovens for either functional or decorative purposes. They also all had the capability to emboss functional or decorative pattern onto their fabrics. As noted earlier, the cost of producing new patterns is high, therefore it may be more feasible to use the hand based methods established within this research for design-led production to enable more frequent changes of pattern. The use of hydro-entanglement was suggested as an alternative means of creating three dimensional pattern or surface effects. Further research needs to be conducted into this area.

The use of coatings to manipulate surface quality and handle was noted by the companies interviewed as an important aspect of their design capabilities. This is an area for further research in regard to the development of nonwoven design.

Lightweight Fabrics

Fabric weight is one of the key engineer-able aspects of nonwovens. The ability to produce very lightweight webs and laminate them to exploit their translucent qualities was an important means of developing the fabric collections within this research. Each of the companies interviewed was capable of producing a range of fabric weights from very sheer (15 – 30 gsm) to heavy dense fabrics (up to 300 gsm). This suggested that developing individual lightweight layers for further manipulation and lamination would be a viable way of producing nonwoven designs within a larger production context.

Colour

Although all of the companies interviewed produced coloured nonwovens, it was apparent that much of the colouration was achieved following fabric production rather than by using coloured fibres. It was noted that production lines are often restricted to using white fibres due to the cleaning required when coloured fibres are employed. This suggested that further research into piece dying techniques, such as cross dyeing and dip dyeing, would be beneficial in regard to developing nonwoven design methods.
**Fibre Type and Quantity**

In regard to the use of natural fibres and fibre blends, although each of the companies indicated that almost any fibre type could be used in production it was apparent that natural fibres were scarcely used owing to issues relating to fibre uniformity and subsequent fabric quality. In relation to fibre quantity it was noted that to set up industrial scale production lines for manufacture, a large quantity of fibre, beyond that required for the actual amount of fabric to be produced, is needed. The requirement to run large scale lines until fabric consistency is correct and consistent, points to potential problems in regard to material costs compared to actual fabric output, particularly if using luxury fibre for comparatively short runs. It was suggested that to produce 100m of fabric a further 50m would be produced during the set up and stabilization of the production line.

**Production Scale and Volume**

In each discussion with nonwoven manufacturers it was highlighted that the volumes of fabric required within the design sector did not fit with their current production rates. It was suggested that full scale industrial production would not be appropriate unless the volumes were high which does not equate with the niche nature of high-end textile markets. It was suggested that pilot scale production or specialist commission processors would be the most appropriate approach to production owing to the sheer amount of volume required to make running the full scale lines economically viable.

It was highlighted that in order for a manufacturer to take on pilot scale production for the design sector, the success of the fabrics within the market would need to be produced because of the costs involved in commercializing even a pilot line. It was suggested that getting a major retailer on board with the product would aid this process. In order to explore these possibilities gaining feedback on the nonwovens produced within the work from high-street retail buyers and designers would be beneficial in pursuing commercial partnerships with industry.

Although the nonwoven manufacturers interviewed were willing to discuss production possibilities, this aspect of the discussion highlighted a current lack of contextual fit between the high-end design sector and the nonwovens industry and pointed to the key issue of accessing equipment to produce fabrics, in particular the difficulty of accessing equipment with which to work.
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9.3 Further Research  
The results of the work conducted in response to each of the research questions highlighted areas in which further research would be beneficial to the development of nonwovens design. Areas for further research that have been identified in regard to each question are summarized below.

1. The development of hand-based methods of producing nonwovens proved a successful means of enabling the researcher/designer to obtain hands on understanding of the way in which nonwoven fabrics are constructed. This in turn, informed design development in regard to nonwovens. While thermal and chemical bonding methods were established within the work, it is suggested that more extensive research into these methods to enable consistent results to be achieved would be beneficial. Further to this, the establishment of other hand-based web forming and web bonding methods, for example wet-lay web forming methods and mechanical bonding methods, would be beneficial in enabling designers and makers to approach a wider range of nonwoven technologies.

2. In regard to the manipulation of pilot scale sampling procedures for design purposes, the work in this thesis focused upon the web forming stage of nonwoven production and thermal bonding methods that utilize heat and pressure. Since the dry-laid web forming process can be followed by any number of bonding processes it was felt that the results achieved would have a wider application within industry. Further research into alternative means of bonding the webs produced would be beneficial to enable the design concepts developed to be applied more broadly within the nonwovens industry.

3. The research conducted enabled nonwovens to be designed and developed specifically for decorative finishing. This ability to do this was identified as one of the unique aspects of designing for nonwovens. Whilst the dévoré technique that was established proved a successful and consistent means of producing unique surface effects, the laser techniques employed were less resolved. Due to the ecological benefits of laser processes further study into the use of laser techniques to etch areas of nonwovens constructed from various fibre layers would be beneficial to the development of sustainable working methods within this area of textile design. Alternatively the exploration of other methods of fibre removal, such as enzyme treatment, could form a significant area for further research.

4. The qualitative nature of the analysis presented in response to the fourth research question provides a new perspective on the design value of nonwovens. The analysis identified that
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Further research into the perceptions of nonwovens held by professionals and consumers within design sector is needed. The work highlighted that in traditional interior markets, high value is not presently attributed to nonwovens in the same way as it is to traditional fabric structures. It would be of interest to study whether or not, alongside design development, greater consumer understanding of nonwovens, the use of luxury fibres and an explicit association between the fabrics in question and a creative individual, as suggested by Rees (1997), would increase the perceived value of nonwovens within the design sector. Such research may, as Papanek (1985) suggests, enable the associational aspects of nonwovens to be re-designed and their applications and markets expanded.

5. Areas in which further research would be beneficial to enable nonwovens to be designed more suitably for industrial manufacture were identified in the interview discussions with nonwoven manufacturers. In regard to colour, the nature of industrial production suggests that further research into piece dyeing techniques such as dip dyeing and cross dyeing would be beneficial. To successfully employ the finishing processes established within the work on an industrial level, further research into the opportunities and limitations of industrial finishing processes would be required.

6. To further establish the possibilities of commercializing pilot scale nonwovens lines, gaining feedback on the design concepts proposed in this work from high-street retail buyers and designers would be beneficial in pursuing commercial partnerships with industry.

9.4 Research Output and Dissemination

The results of the research presented in this thesis have been presented through the following conference papers and industry presentations;

- 'Designing for Nonwovens — Industrial and Craft Perspectives', F. Kane, Autex Conference, North Carolina University, USA 11th – 14th June 2006
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- 'Textiles and Translation', T. Kavanagh, S. Bartlett and F. Kane, Creativity Meets Technology Conference, Philadelphia University, USA, 10th – 11th May 2004

The material outcomes of the research have been presented through inclusion in the following exhibitions:


- Nonwoven fabric collections shown at – Nonwovens Network Annual Seminar, Leeds, June 2005


9.5 Chapter Summary

This chapter has outlined the main areas of work presented in this thesis and the key findings in relation to the central research questions. In doing so, the contributions to knowledge made through the research have been drawn out and areas of further work have been identified.

The areas in which the research findings contribute to new knowledge are summarized below:

- The establishment of a historical, technical and contextual framework in regard to nonwoven fabric design – the literature review presented in this thesis brought together historical, technical and contextual information in regard to nonwoven fabric design in a way that is not currently documented in present literature.

- The establishment of hand based methods of production that relate directly to industrial nonwovens technologies – hand-based methods of dry-laid web formation and chemical bonding methods were established enabling hands-on knowledge to be developed.

- New understanding of design possibilities at the web forming stage of nonwoven production when employing dry-laid methods has been developed–
methods of incorporating a wide range of materials between fibre layers were established, key considerations to enable consistent production on a small scale production level were identified and the development of webs made from contrasting fibre layers for further processing was established.

- The adaptation of devoré printing and laser marking techniques for nonwovens made from a range of fibre types, specific constructions and with additional materials embedded within their structure – the methods of devoré and laser marking established enabled optimum fabric quality to be retained and contrasting surface effects to be achieved resulting in unique and new nonwoven fabric designs.

- The appeal of the nonwoven fabric designs within high-end markets assessed from a qualitative perspective – the qualitative approach taken within the research to gain external review on the fabrics produced enabled a number of key factors in regard to the value attributed to nonwovens within the high-end interiors market to be identified, further to this their suitability from an aesthetic perspective for this market was confirmed.

- Feasibility of producing the nonwoven designs developed within the present nonwovens Industry assessed from a qualitative perspective – key issues that designers working with nonwoven technologies need to be aware of and sensitive to, to enable designs that are relevant for commercialisation to be developed were identified.


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