Structural Textiles: Adaptable Form and Surface in Three Dimensions

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Copyright statement

Abstract

My PhD research develops production processes incorporating origami folding, shibori, additive printing and fusing techniques to create textiles that sustain three-dimensional, adaptable form with little or no supporting substructure. In these materials the textile surface itself becomes structural.

The controlled packing, deployment and structural stability offered by predetermined folds in planar surfaces are extremely beneficial in many situations e.g. engineering, architecture and product design. I have devised transferable templates of folding that can be reinterpreted in a variety of material weights and scales that have potential for application in a number of these areas. The inherent mobility of these structural textiles, combined with the judicious choice of substrate and materials applied through printing and fusing, enables properties such as thermal or sound insulation, electrical conductivity or light transmission to be varied, as the situation demands. The textiles created are not only autonomous physical entities but also speculative design models.

Such developments more usually originate from material science, engineering and textile technology contexts. However, by building on research carried out by these disciplines to develop folded structures but emphasising a ‘poetic’, design-orientated outlook I explore the potential for a more intuitive, non-linear approach to highlight hitherto overlooked elements in the design process.

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Film 3 – Hexagon print self-folding polyester lycra, sample 34, (no soundtrack), 2006/07.

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Film 6 – Fictionalised folds, circular format, (no soundtrack), 2008/09.

Film 7 – Fictionalised folds, full wall projection format, (no soundtrack), 2008/09.

PDF format database of textile samples

PDF format database of base materials

Viewing instructions for accompanying materials

Throughout the thesis I make references to video material, included in DVD format, as well as textile samples created as part of the research. Full details of each sample can be found on the electronic database included in PDF format on the DVD. In the text each textile sample is identified by '❖' followed by the sample number. Video material is denoted by '★' followed by the video number. All videos except the first have no soundtrack.

Acknowledgments

This research would not have been possible were it not for the help of a diverse range of people whom I would like to thank for their invaluable assistance.

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The AHRC, EPSRC, RCA and the Textile Institute have all provided material support for the project in the form of grants and bursaries that have enabled me to focus intensively on my research as well as to travel to visit key people, conferences and industrial facilities that otherwise would have been inaccessible to me.

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Author's Declaration

During the period of registered study in which this thesis was prepared the author has not been registered for any other academic award or qualification.

The material included in this thesis has not been submitted wholly or in part for any academic award or qualification other than that for which it is now submitted.

Rachel Philpott
March 2011

CHAPTER 01

Chapter 1: Introduction

Project background & overview

This thesis is derived from a programme of empirical research that is grounded in practical experimentation centred on folding and situated within the discipline of Textiles. The aim of the project was to develop production processes for the creation of novel, textile type materials, capable of sustaining three-dimensional, adaptable form with little or no supporting substructures.

The controlled packing and deployment, and the structural stability offered by predetermined folds in three-dimensional structures are extremely beneficial in many situations: articles such as umbrellas have been in use for many centuries. The predictable loads and stresses of more precisely folded origami type structures combined with the benefits of their transformable, compressible shape make them useful in applications as diverse as space exploration, where they are employed as booms, and medicine where they are used as stents for bodily implantation. The variety of application of such structures amply illustrates the advantages given by the transferability of basic templates of folding to wide-ranging scales. At present these folded textile structures are usually a two-part construction of ‘mesh & membrane’. The creation of a self-supporting textile that integrates the ‘mesh’ and the ‘membrane’ into a single, streamlined system eliminates any risk of the misalignment or disconnection presented by the two-system structure and potentially confers an improved aesthetic to the resultant material.

To date such developments have more usually originated from material science, engineering and textile technology contexts. However, by building on research carried out by these disciplines to develop folded structures but emphasising a ‘poetic’, design-orientated outlook I explore the potential for a more intuitive, non-linear approach to highlight hitherto overlooked elements in the design process. By using diverse methods such as studio practice, analytical and creative writing, drawing and film making to compliment the development of the textiles at the core of the research a single concept can be explored from multiple viewpoints. Through the use of such a range of methods seemingly unrelated ideas can be juxtaposed, the cross-pollination creating opportunities for innovation. The personal and subjective aspects of this approach facilitate examination of emotional and imaginative perspectives alongside technical considerations in ways that can suggest alternative directions of development, broadening the impact of the research beyond purely technical performance issues to include its experiential and expressive aspects.

In this project intuitive physical engagement with the unpredictable and dynamic materiality of textiles is key, leading me to consider if such interactions lead to a particularly 'textile' way of thinking characterized by malleable, folded and connective modes of thought. This contributes to the current debate regarding the value of applying textile methodologies to the solution of problems in interdisciplinary contexts.

The research project has grown from my educational and professional experience in the area of printed textiles. I developed skills specific to the production of printed textiles for fashion and interiors through education to BA level as well as through industry experience gained at a number of studios and several years freelance design practice. I expanded my expertise to include fine art printmaking whilst managing a printmaking studio in an educational environment. Here I also embraced interdisciplinary practice, specifically working with wood, metal and plastics using techniques such as etching and vacuum forming. Applying this broad range of skills and approaches to evolve 3-D textile printing processes I began to develop textile substrates that displayed pronounced three-dimensional aspects.

The focus for this process-led project evolved as the research progressed. My starting point was the development of printed and manipulated textile processes to create self-supporting, three-dimensional textile forms with a variety of potential applications. 3-D knit and weave displaying these qualities are already established textile technologies but 3-D printed textile techniques have yet to be fully explored. Initial experiments were undertaken using silk-screen printing as a primary method, combined with techniques such as stitch and origami folding. However, the three-dimensional samples produced demonstrated unforeseen potential for transformative or adaptive behaviour due to the structural qualities imparted by their folded surfaces.

Adjustment of boundary tension of many of these samples caused the textile to deploy from a 'packed' state to a complex 3-D structure in which structural integrity was provided by the printed and folded areas. The significant structural changes to the textile given by the folds had consequent changes on the physical properties of the material e.g. light transmission and thermal insulation. Viewed as scale models they suggested unanticipated ranges of applications that became the focus for further development throughout the research period.

The project has investigated the potential of techniques such as heat setting, printing, bonding and laminating to create adaptable and self-supporting folded structure on a variety of textile substrates. I have explored the potential for the integration of origami-based patterns with alternative types of folding to create novel three-dimensional forms. As I have approached the research from a textile design perspective I have consciously prioritised the tactile and aesthetic aspects of the materials created. However, the three-dimensional aspects of the textiles produced are not purely decorative but also enhance their functionality. Practical work is predominantly monochrome to allow for greater focus on form and texture; an exploration of the effects of colour on perceptions of form may follow in future work.

The interface between the many disciplines explored in this interdisciplinary research has provided a rich source of inspiration. Adoption and adaptation of techniques from disciplines such as product design and architecture has enriched my textile practice, broadening the range of production techniques available to me as well as profoundly affecting the conceptual development of the project.

Aims and objectives

The project's aims and objectives were developed to enable the methodical investigation and evolution of three-dimensional textile structures. The research focused on the development of textile production processes; particularly those that create permanent pleats and folds. It also explored adaptation of textile-type materials such as non-woven polyesters that were especially effective for the creation of such forms due to their customisability. The project aims and objective are as follows:

Aim 1: To develop an insight into contemporary design, production and application of three-dimensional, adaptable and self-supporting folded structures:

- Explore generic principles underlying the folding patterns of adaptable and deployable structures.
- Identify the range of present application for such structures.
- Identify and analyse current, cross-disciplinary, industrial production processes and materials that are suitable for the creation of permanent, self-supporting folds on textile substrates.

Aim 2: To develop adaptable and self-supporting, three-dimensional structures, as well as production processes and materials for the realisation of these structures as textile forms.

- Identify suitable materials for the realisation of three-dimensional textile forms and, where necessary, develop new materials.
- Adopt and adapt current industrial production processes and, where necessary, devise new processes for the creation of adaptable and self-supporting folded textile based form.
- Evaluate the forms created against criteria devised in response to the contextual review.

Aim 3: To develop a research methodology that can encompass both the theoretical and practical aspects of the research project.

- Explore and evaluate existing textile design approaches, adopting those methods that prove suitable for this research.

- Examine research methodologies from other disciplines to see if these could be used wholly or partly for the implementation of the project.
- Develop a coherent methodology appropriate to the project that encompasses both its poetic and pragmatic aspects.
- Evaluate the effectiveness of the research methodology.

Summary of methodology

I have employed a 'bricolage' of methods to complete this process led research, using the multiple perspectives this approach gives to scrutinize the project from different viewpoints. The project has drawn upon my detailed specialist knowledge of textiles design and production processes with a particular emphasis on print, and has used a variety of textile and non-textile techniques and materials.

The research has employed my skills as a textile designer in an interdisciplinary context to re-evaluate and develop processes for the development of adaptable, three-dimensional, textile type materials that have hitherto been more usually created by textiles engineers. The textiles developed through this approach are not exclusively defined by their technical aspects and applied functionality but take other factors into consideration, for example their aesthetic and emotional effects. Although some aspects of the production is mechanised I combine this with hand making to enhance opportunities for the development of holistic, embodied knowledge and emotional engagement with the textiles created.

Studio-based practice has been key to the progression of the research. Integrating hand and CAD/CAM techniques I have created physical samples to explore and advance concepts and processes as well as form. My direct practical engagement through making has enabled deeper understanding of the technical limitations of both the production processes and the physical properties of materials. This has allowed inspiration to be provided by unexpected results. Knowledge has been developed through the systematic testing of materials and process as well as by observation, analysis and evaluation of outcomes. A database recording the procedure for making each sample and evaluating the outcomes has been constructed both as a paper-based resource and in a searchable electronic format, which has informed subsequent practice. The resultant textile forms function both as functional textile pieces and as conceptual models that suggest potential development of properties such as self-actuation in response to environmental conditions or future applications, for example active sportswear fabrics or self-deploying solar panels.

In order to understand the textile artefacts at the centre of the research I have had to analyse the complex and embodied making process as well as examine the outcomes from a point of separation and distance. I have used drawing, photography and video production pragmatically to collect and record production processes and data as well as to develop ideas through imaginative creative practice. Visualisations using hand drawn and computer-generated image, film and animation have been important for the evolution of both physical form and concept as well as for dissemination of the research.

Writing has been used throughout the project to document, analyse and comment on work undertaken as well as to explore and evolve concept. I have used a reflective journal to capture and chronologically record ideas and information, which has enabled the constant review and adjustment of both concept and practice. The use of creative writing techniques has also aided the structuring of thought and the communication of ideas. These various writing practices have been collectively employed to enable the completion of this thesis.

I have consulted select specialist practitioners from the disciplines of architecture, materials science and engineering to explore the potential of current technological developments and to aid identification of optimum substrates and techniques for manipulation. Discussion with fine artists and designers has influenced the evolution of methods that surface the more poetic aspects of the project. Exhibition of the physical outcomes of the research and presentation of key concepts at conferences and symposiums and the resultant feedback has also contributed to the development of the work.

In order to contextualise the project I have had to consider the various philosophical and cultural conventions that have influenced the research design. The contextual survey and critical review have included a literature survey, visits to exhibitions, conferences, trade fairs, research and industrial facilities. I have evaluated and analysed data collected using both critical writing and visual methods. I have examined the historical context and current usage of technologies and materials that create folded form both within the discipline of textiles and in other areas ranging from architecture to medicine in order to inform the development of concept and outcome in my own practice. An examination of 'smart' or 'performance' textiles for the creation of integrated, dynamic systems and their use across a range of disciplines, including architectural and spatial design, has suggested areas in which the research could be developed in the future.

The organisation of the research into a taxonomical structure that categorises the information collected and samples developed into an overarching structure that differentiates production methods and integrates contextual references has provided a creative tool for the generation of subsequent samples.

Summary of thesis content

Chapter 2 – ‘Striated research and the evolution of a cohesive methodology’ considers the influence of folding, biological models and pattern in the development of my three-dimensional textile forms. It goes on to discuss the situating of my research at the boundaries of art, design and science, and the use of ‘bricolage’ to represent fully all these different aspects and perspectives. It also contemplates how philosophical discourse on folding, particularly Deleuze’s emphasis on connectivity, flexibility and infinite variety have influenced the research.

Chapter 3 – ‘Playful practice in containing creases’ considers the necessity to achieve balance between free playful exploration and containing boundaries in order for creative practice to flourish and advance beyond established methods. It then outlines my journey from overly constrained pragmatic practice to freer approaches using methods including drawing, writing, photography and video. It describes the organisation of these multiple methods in a variety of archives and databases, a process that eventually led to the development of an overarching taxonomic tool that provides a structuring principle for the generation of new work.

Chapter 4 – ‘Folding towards 3-D form’ outlines historical and modern production and application of folded textiles. It then describes my own use of stitched and tied manipulation techniques as well as discussing factors governing my selection of materials and my reasons for creating predominantly white work. It goes on to describe my practical exploration of origami folding on textiles, including an overview of current industrial practice and opportunities for development of these techniques. It also surveys recent practice in diverse disciplines that uses origami type folding and considers how aspects of these could be adapted to apply to my own textile practice.

Chapter 5 – ‘Entwined thinking, enfolded practice’ explores the particular position of textiles in relation to current discourse on design thinking. It considers how different disciplinary approaches impact on practical and conceptual development, paying particular attention to overlapping methods in textiles and architecture. It outlines practical work using silk-screen printing to create both self-folding and origami folded textiles. It goes on to note how my exposure to different disciplinary approaches altered my perception of my practice, resulting in a modification of my original intentions to reflect the new potentials seen in the work.

Chapter 6 – ‘Pliant process and embodied making’ considers the importance of touch and sensual knowledge in acquiring understanding of textile artefacts and the value of these ways of knowing to the textile design process. It goes on to discuss the opportunities and disadvantages presented by disembodied digital technologies to this process, exploring how tacit and embodied knowledge can be preserved as part of textile practice whilst still exploiting the potential of CAD/ CAM to create complex outcomes. It subsequently outlines practice using laser cutting, lamination and bonding techniques for the creation of larger-scale, self-supporting deployable textile structures. It finally discusses my use of touch to guide my making, the emotions that this physical sensation surfaces in the design process and the ways in which this non-verbal knowledge can be communicated to others.

Chapter 7 – 'Folding towards the core' considers the effectiveness of the methods used to conduct the study and evaluates the outcomes of the research. It notes the wide potential for application of the textile forms created while acknowledging that the outcomes predominantly function as illustrations of imagined future outcomes rather than as working prototypes. The chapter discusses the significance of these pieces as exemplars of general process and material systems underlying the generation of folded textile forms and suggests possible future directions for further research.

CHAPTER 02

Chapter 2: Striated research and the evolution of a cohesive methodology

This chapter considers the principles that have influenced the development of 3-D form throughout the project and outlines the methodology used to complete the research, which has been informed in part by philosophical discourse on folding.

The evolution of form

Folding is inherent to the stuff of textiles. The propensity of fabric to drape and crease is key to its versatility. In ancient Greece cloth, being too valuable to cut, was simply folded and wrapped around the body to form a simple tunic called a 'chiton' (fig 1). This practical garment created flowing folds that eased movement but relied on belts, broaches and pins to mould their shape around the body. In similar fashion but in an architectural context, Shigeru Ban uses the ductile properties of cloth to reconfigure the usually static walls of an abode into a series of dynamic loose folds in his 1997 Curtain Wall House (Hodge et al. 2006, pp.52-55) (fig 2). Christo and Jeanne-Claude's wrapped, draped and tied textiles (fig 3) emphasise the aesthetic and symbolic potential of such folds from a fine art perspective, swathing objects from trees and buildings to whole islands. These examples from

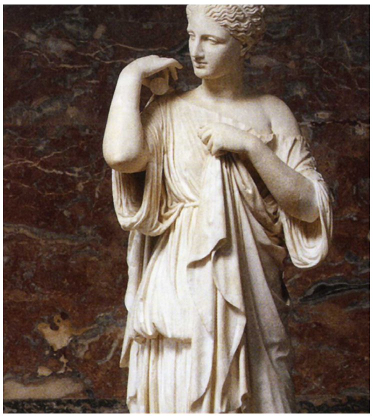


Fig 1. Marble statue of Diana, wearing a chiton. Roman, after original of 346BC. Musée de Louvre, Paris.
Fig 2. Curtain Wall house, Shigeru Ban, 1997.
Fig 3. Wrapped Trees, Fondation Beyeler and Berower Park, Riehen, Switzerland, Christo and Jeanne-Claude, 1997-98.

widely varying discipline illustrate that freely draped textiles are functional, adaptable and aesthetic, all attributes that are relevant to this project. However, the applications of such loosely controlled folds are limited as they rely on the support of an underlying scaffold, ties and fixings to attain their shape. They are not structural.

Using a slightly different approach carefully placed folds can stiffen flexible textile materials allowing the transformation of 2-D plane to 3-D form without a supporting substructure. For example, darts and tucks can mould substrates by reducing surface area to create 3-D shape (fig 4). Conversely the gathering of puff sleeves and ruffled collars exploit the sculptural effects of folding to maximise surface area and expand space (Koda 2003) (figs 5 & 6). Many other examples of textile folding techniques are discussed in more detail in chapter 4, 5 & 6. In such instances the folded shape of the textile is no longer dictated by the form beneath but has become structural, describing a connected yet independent form. It is this structural capability of folded textiles that I aimed to exploit and develop to create dynamic, deployable 3-D forms.

Folding manipulates interactions between the material’s own interior and exterior surfaces, bodies and space. On a superficial level it divides continuous plane into discreet systems, partitioning surface into separate parts.

> “The fold both flattens and animates; it folds elements together on a continuous plane while differentiating the same surface.” (Cobb 2004, p.111)

This simple act transforms depth, width and length, alters volume. Yet in dividing one surface into many the boundary of surface becomes blurred. Surface becomes planar form, its structure merging

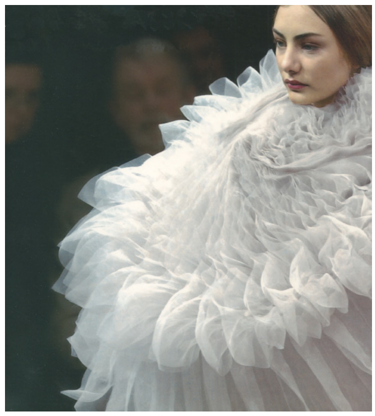


Fig 4. A series of cubes formed by using darts to manipulate the fabric into a 3D form.
Fig 5. Reception Dress with gigot sleeves, Charles Frederick Worth, c. 1892.
Fig 6. Polyester organdie ruff, Junya Watanabe for Comme des Garçons, 2000.

interior and exterior into an unbroken and continuous whole, leading to ambiguity. The single entity is differentiated not by difference but by the striation of the fold, back becomes front becomes back and, with surface folded in on itself, outside becomes inside.

> 'The outside is not a fixed limit but a moving matter animated by peristaltic movements, folds and foldings that together make up an inside: they are not something other than the outside, but precisely the inside of the outside.' (Deleuze 2006a, pp.96-97)

The folded surface is defined relative to itself and due to the transformative nature of the fold these relationships are liable to change.

The folded planar forms in this research have grown organically. Echoing biological patterns of evolution they have been generated through an epigenetic process of progressive differentiation, a gradual accumulation of successive layers of materiality and process. D'Arcy Wentworth Thompson (1917) describes a developmental paradigm where gradual difference in degree becomes difference in kind. For example, a bump in a reptilian jaw shifts over thousands of years to become a bone in the middle ear; thus the same element, by forging a different relationship to the whole changes its functionality. Deleuze sees such biological developments as a series of progressive, generative folds.

> "Folding – unfolding no longer simply means tension – release, contraction – dilation, but enveloping – developing, involution – evolution. The organism is defined by its ability to fold its own parts and to unfold them, not to infinity, but to a degree of development assigned to each species." (Deleuze 2006b, p.9)

In a similar evolution, the progressive iteration of a basic design concept can metamorphosize into the development of numerous transformable forms, transferable to countless potential applications. Demonstrating that on both physical and conceptual levels, "The multiple is not only what has many parts but also what is folded in many ways." (Ibid, p3)

At the beginning of the research the success of my textile samples was predominantly judged by the magnitude of structural depth and their aesthetic. As the focus of the project progressed from the creation of 3-D structure to the production of transformable and deployable forms these criteria were revised. The aesthetic of the work remained extremely important but efficiency of form now had to be considered as well as the suitability of materials for particular functions. Natural deployable structures generally aim to use the minimum of materials to create the greatest possible deployed surface area, for example to maximise photosynthesis or absorption of nutrients (Vincent 2002b, pp.1-2). Using similar criteria, kinetic models were evaluated regarding the ease of deployment and retraction as well as the ratio of packed to open surface. The effectiveness of hinged and planar areas at maintaining their structural integrity was tested empirically. Structural elements had to stiffen the structure without collapsing under their own weight. Hinges had to be robust enough to support the planar surfaces without sagging or tearing as well as demonstrate shape memory capabilities and the necessary range of movement to perform effectively. Modifications were made as necessary to improve the stability, stiffness, strength and aesthetic of the structures.

My approach to the development of form is often improvisational with motif and structure generated intuitively from physical experimentation. Both designed motif and the gestures of making are constantly repeated as my textiles develop. It is a metamorphic practice where designs are generated, analyzed and evaluated; process and form evolving as insights gained through the practice delineate the parameters for subsequent models. Each work is an iteration of those that have gone before as well as a precursor of those to come, every repetition deviating slightly from its predecessor.

> "The power of repetition appears not in the perfection that results but in precisely the opposite, in the imperfection that inevitably appears." (Hemmings 2007, p.69)

Even within a single sample recurring motifs are imperfect clones of their neighbours, modules being self-similar rather than identical copies. A gesture is never exactly replicated in every detail. The physicality of the material also has its impact. For example, as discussed in chapter 4, when transferred onto cloth tessellated origami units distort as the piece size increases. Within these divergent repetitions, imitations and emulations lie potential for creativity. Various solutions to the problem of creating large piece sizes of origami folded textiles are outlined in chapters 5 & 6.

As in nature, some advances in this research do not arise as sequential iterations designed to address evolving environmental or behavioural needs but are random or chance occurrences adopted for previously unforeseen uses. Evolution can happen as a result of human error or 'happy accident', where processes and materials behave unpredictably resulting in new forms and processes. For example, the outcome of a mistaken substitution of print paste is outlined in chapter 4, demonstrating how inconsistencies in the making process can give potential for innovation (these ideas are discussed further in chapter 6). However such spontaneous, improvisational and accidental methods used in isolation would be too open-ended to generate useable results in a timely fashion. In order to advance with optimum efficiency a balance must be struck between planned and unplanned ways of working. Laithwaite (1994) says, "Utopia, it appears, lies between perfect order and perfect chaos." My design process merges spontaneous, process led approaches with pre-planned, goal driven and ordered methods.

The repetitive motifs of my printed-textile design practice have been carried over into this research. The mirrored, glided and rotated symmetries of pattern I once used to create decorative textile lengths are now used as a structuring principle for the creation of form. Textile pattern is predominantly read as two-dimensional surface semiology or symbolic marker and often seen as an 'additionally joined' accessory (Kraft 2004, p.279), of secondary importance to the object form. However, it is only by "Neglecting materiality of ornament and patterns [that] they become abstract and flat pure form." (Ibid, p.278-9) Here I use pattern as material building block, focusing on how it contributes to form and structure rather than what it symbolises or represents. Kraft sees this 'structural' pattern as inherent in textiles.

> "The repetition of working units, whether understood as a repeat, or not, generates the textile object. Consequently all textile techniques are based on the idea of patterning: an isolated unit (repeat) is repeated with potential infinity. So we can state: patterns are not accidental but substantive to textiles." (Ibid, p.281)

In a subversion of the modernist ideal 'form follows function' my forms follow pattern. In this approach, inherent in textile practice, ornament is not superfluous crime but intrinsic structure.

The potentially infinite repeat is often bounded by technical constraints: limits to piece size of complex origami folded textiles are discussed in chapter 4. In my work the termination of the potentially endless repetition of larger pieces is often determined by the physical limitation of equipment and materials used in their production. Heat presses are only so large, rolls of material only so wide. In small samples economy of time and materials is of prime importance. I produce the minimal number of modules required to give a sense of how grouped units will perform.

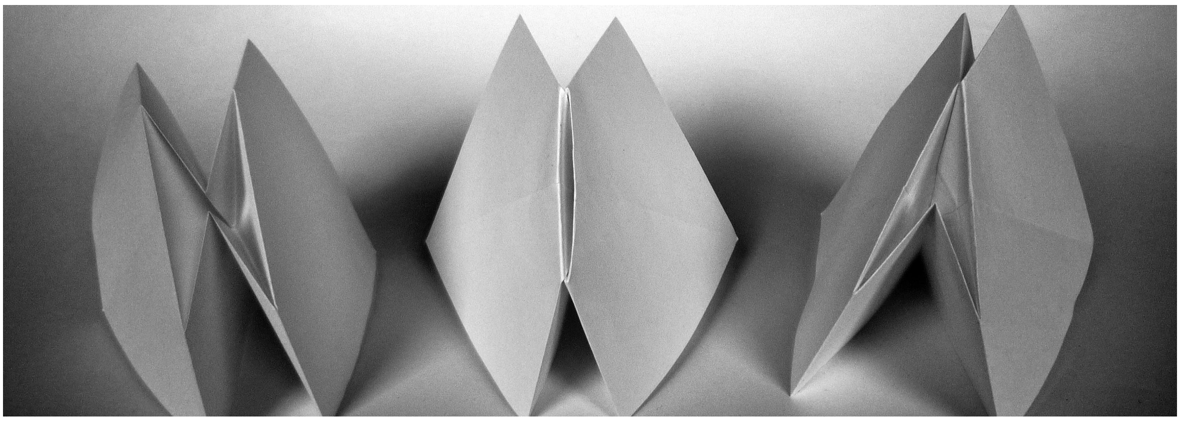


Fig 7. From left to right: open sink fold, closed sink fold and mixed sink fold.

The individual module or pattern motif sets the measurements, rhythm, pattern and behaviour of the entire structure. By managing the form, material and behaviour of the single unit one is able to control the complexity of a larger structure. Modularly segmented forms can be easier to produce, transport and assemble. They can also be more easily customised both locally at specific points in the structure and globally across the whole form. By combining non-identical modules to create a-periodic pattern one can also increase the potential for adaptation by integrating a range of shapes or structural behaviours into a single form.

No basic origami fold demonstrates this better than the family of ‘sink’ folds, specifically open, closed and mixed sinks (fig 7). While all these folds share an identical folding pattern, changing the order in which the layers are folded significantly alters the behaviour of the resultant module.

> “The open sink is a simple inversion of a corner formed from a region in the interior of the paper… The line of the sink is a mountain fold, which runs all the way around the point being sunk like a road girdling a mountain peak. All of the creases above the sink line get converted to the opposite parity, mountain to valley, valley to mountain.” (Lang 2003, pp.32-37)

To perform an open sink fold the apex of the corner to be sunk is opened out flat before creasing the mountain fold (fig 49) that demarcates the depth of the sink and inverting the point. The resultant form is mobile and springy. With a closed sink fold, although the pattern formed by pre-creasing is identical the apex remains folded while inverted, producing a locked structure. This minor difference in execution alters layer order, dramatically transforming the outcome from dynamic to rigid form. Mixed sink folds are a hybrid form, combining elements of both open and closed sinks to form a partially open structure. We can perhaps more easily understand this concept by comparison with linear knots.



Fig 8. Figure of eight knot used in rock climbing.
Fig 9. Tree bark design motif.
Fig 10. Hornbeam leaf.

To make the safe, locking figure of eight knot used in rock climbing (fig 8) it is essential that the rope passes over and under itself, through its self-created loops in a particular order or it will unravel under tension. Closed sink folds are planar knots, engaging comparable principles but using surfaces not lines. These intriguing sink folds provide the basis for many samples (36-39, 82, 86, 98), discussed further in chapters 5 & 6.

I have used biological analogies to develop a deeper understanding of the mechanisms of structural form so I might efficiently devise and adapt 3-D designs for varied application. Natural form is a common source of aesthetic inspiration for textile designers and has inspired the motif based on tree bark (fig 9), used in samples 4-12 (discussed further in chapter 4). However I had to integrate structural thinking into my textile design practice to realise my goal of creating 3-D planar forms, moving beyond purely aesthetic considerations. By investigating analogous folded structures in nature and isolating and abstracting rules governing both the modular pattern and the whole structure I was able to refine the parameters within which I developed my own forms. I have sought examples of structural folding that create 3-D form from planar surface, for instances of the variable rigidification of surface and for kinetic configurations capable of movement.

Frequently in my own practice, connections between my designs and comparable forms have only been recognised after samples had been made. A number of similar ‘post-production’ analogies have been made in photographic studies outlined in chapter 3. Nonetheless, identifying such connections allows me to adjust designs for optimal performance through analysis of how these analogous structures achieve their strength and stability as well as efficient packing and deployment. Observing nature can provide validation of the structural soundness of designs for those without engineering expertise as it demonstrates numerous examples of optimally functioning, materially economical structural systems. Such biological examples can also elucidate previously unnoticed detail in patterns of structural organisation.

One such example is the hornbeam leaf (fig 10). I used variations of ha-ori, or leaf folding for the simple fold structures of samples 43, 44, 47, 52, 58a, 85 and 96. This leaf also provides the design inspiration for Student’s ‘Ha-Ori’ shelter that is discussed further in chapter 4 (fig 70). Vincent notes,

> “the leaves of hornbeam and beech have a straight central (primary, main) vein and symmetrically arranged parallel lateral (secondary) veins which generate a corrugated surface which can be considered as a segment of Muira-Ori or a ha-ori (lit. leaf folding).” (Vincent 2002a, p6)

The corrugated parallelograms that make up the leaf surface allow the structure to deploy when pressure is applied to a single, central point in the form. As the leaf opens and the folds become shallower there is a tendency for the surface to lose rigidity and curve. This effect is mitigated by the straight main stem that intersects the corrugated folds of the lateral veins, adding stiffness along the axis of symmetry. The counterpart origami structure repeats the pattern across a surface to effectively create numerous 'main stems'. Rigidity is achieved by the continuity of the folds throughout the structure even when the direction of fold is altered so that top surface becomes side surface. Increasing the depth of the folds increases the resistance of the structure to bending movements.

It is interesting to note a higher angle of fold in relation to the central leaf rib, for example 80˚ rather than 30˚ results in more compact packed states. These structures also take longer to achieve a fully deployed state, remaining relatively compact until the last stages of deployment. A leaf in which the secondary veins approximate a 30˚ angle has a greater surface area at all stages of opening except when fully deployed. So, adjustment of this angle in a similarly folded design alters packing behaviour and with it, potential functionality.

Using general structural and behavioural patterns rather than specific details as design inspiration allows aspects of my design practice e.g. materiality to impact on the outcome, increasing the potential to find novel solutions. For example, the printing and laminating processes outlined in chapters 5 & 6 create structures that are an inversion of the natural formation of leaves. Instead of stiffened stems bridged by soft, flexible planar areas these samples stiffen the planar surfaces leaving the 'stems' or hinge points pliable.

Tessellated geometrical form underpins planar, crystalline and sponge like structures as diverse as Buckminster Fuller's geodesic dome, snowflakes and polymeric auxetic materials. Auxetic materials are 3-D honeycomb structures that display the unusual characteristic of getting fatter rather than thinner when stretched. When compressed there is a similarly counter-intuitive all over contraction of dimension and the material becomes denser, making them ideal for safety critical items such as body armour, crash helmets, and seat belts due to their enhanced impact absorption properties (Alderson 2006). The geometric arrangements and behaviour of some auxetic materials are comparable to a number of origami folding patterns used in this research, which also expand across the entire surface when stretched in a single direction, although the expansion is confined to two dimensions. When such modules are tessellated horizontally, vertically or radially across a 2-D plane a plethora of forms, including tower and dome structures can be created that expand across their entire surface area, thereby correspondingly increasing enclosed volumes with minimal energy required for actuation.

In the movement of such structures we begin to see recurring pattern not as a series of identically replicated objects but as a continuous, interconnected and adaptable system.

> "A module never works alone but as an aggregation of a multitude of instances. Thus the whole emerges out of the interaction of a series of individual objects." (Tessmann 2009, p.52)

The use of non-identical modules in such systems gives a greater segmentation of the structure, which in turn allows for heterogeneous, localised adjustments that differentiate areas within the whole. In the creation of the fold the material is generally passive, acted upon by external forces. However, in some instances materials with oppositional behaviours create physical systems that become self-folding. The introduction of irregularity and differentiation to such systems leads to the emergent, self-organisational behaviours that are discussed further in chapter 5.

Pliable research practices: evolving a 'textile' methodology

Prior to the commencement of my PhD my design methodology was almost exclusively practice led. Ideas were developed through physical experimentation with materials and process. Form and motif were derived from these experiments in tandem with visual practices such as drawing and photography. External influences came from exhibitions, trade fairs and trend forecasting. My design practice was devoid of the theoretical content necessary to situate it in an academic research context. Embarking on PhD research I had to develop an approach that entwined the theoretical with the practical strands of my research to create a coherent and truthful 'textile' methodology.

Academic models suggesting possible approaches and methods for research-by-practice PhDs have been outlined by Gray & Malins (2004), and Sullivan (2010). Much debate in this area has been generated around the validity of creating and disseminating knowledge by means other than the written exegesis. Considerable discussion surrounding the concept of 'thinking-in-action' has originated from studies of design practice (Harrison (1978), Schön (1995), Cross (2007), & Pallasmaa (2009)).

de Freitas' (2002) investigation of the working methods of postgraduate art and design students demonstrates that the active documentation of studio practice using methods including visual, textual, video and audio documentation can help the practitioner articulate the processes and forces in action when making intuitive decisions in the design process. This documentation provides a significant point of interaction between practice and theory. Talking of 'active documentation' de Freitas states:

> 'As a research method, it is an appropriate hybrid tool for critique, strategic planning, decision-making and exegesis writing. As a method for locating and negotiating theoretical and practical concerns, it could play a role in theory construction relating to art and design research.'

However, it is essential that these documentation methods be systematically integrated with reflective practices in order to evolve the practice in a meaningful way. The validity of such documentation as a credible research method is supported by the work of many designer/researchers. For example, Pedgley (2007) scrutinised a range of self-reportage methods, particularly focusing on diary writing in his PhD centred on technical innovation in industrial design practice. These studies have shown that such methods can be particularly beneficial in situations where the practitioner has to perform a dual role, carrying out practical work whilst simultaneously applying systems of self-analysis. However, a balance must be struck between the immediacy of documentation that occurs concurrent with the practice and post-event reportage, to maximize opportunities for the collection of accurate data whilst minimizing disruption to the design practice being studied. My own struggles to attain this balance are discussed in more detail below and in chapter 3.

I found that my project, although essentially design research, operated at the interstices between many areas. Design and craft practice share many common elements, for example skill in making things by hand. However, the meaning of the word 'craft' goes beyond practical considerations of skill in workmanship to embody a distinct set ideas and approaches. In my practice hand-making skills play an important role in ensuring the production of quality design outputs that will have relevance in the intended cross-disciplinary arena. However, this is not the only aspect of craft practice that is of relevance to me. Craft and design also share non-linear approaches that could be described as 'design thinking' (discussed further below and in chapter 5). In my practice I use craft-based techniques as a source of inspiration for new design thinking. I import techniques such as origami and shibori from craft into design contexts, reinterpreting them using alternative methods and materials in ways that combines both craft-based and industrial methods of production. The outcomes are then offered as models or prototypes for technical application to engineers, architects and designers external to the discipline of textiles.

My project contained both technological and artistic aspects but I had problems situating myself within either the scientific or the artistic arenas, as I appeared to be employing 'soft' artistic thinking around the 'hard' scientific topic of textile technology and futures. However, over time I realised such an approach might strengthen rather than weaken the project. Pennina Barnett employs drapery as a poetic metaphor to illustrate the potential of Deleuze's 'soft' flexible thinking.

> "What if the poetics of cloth were composed of 'soft logics', modes of thought that twist and turn and stretch and fold? And in this movement new encounters were made, beyond the constraints of binaries? The binary offers two possibilities, 'either/ or'; 'soft logics' offer multiple possibilities. They are the realm of the 'and/or' where anything can happen. Binaries exclude: 'soft logics' are to think without excluding" (Barnett 1999, p.26)

Methods employing ‘soft logics’ are often seen as woolly and ill defined with no clearly articulated concept or goal. Its passivity has negative connotations, being influenced by external forces seen as weak. But doesn’t the pliability of ‘soft’ thinking, its openness to include the unforeseen allow more opportunity for the unexpected to occur? Barnett argues,

> “…if ‘soft’ suggests an elastic surface, a tensile quality that yields to pressure, this is not a weakness; for ‘an object that gives in is actually stronger than one that resists, because it also permits the opportunity to be oneself in a new way’” (Ibid, p.26)

The primary stage of my research focused particularly on gaining an understanding of technical textiles and advanced materials as I was interested to see if such materials might be used in tandem with traditional textile processes to advance my own making. However, predominantly artistic projects also sparked ideas for me, as did both academic and creative writings. Unsure how to balance these differing traits and guided by earlier doctoral research in textiles I started by undertaking a number of practical experiments adopting a scientific style that dismissed unquantifiable data in favour of analysable facts regarding production processes and material behaviours. However, it soon became apparent that this method would elucidate only one aspect of what I hoped would be a much more rounded and complex project. While quantitative methods have a place in my work, particularly in the development of material substrates for folding, they needed to be integrated into the wider fabric of the research, complimented by a range of artistic methods. As Laurel Richardson says,

> “Science is one lens; creative arts another. We see more deeply using two lenses.“ (Richardson, 2000, p.937).

I needed to adjust my ideas of ‘proper’ research to allow myself to investigate the less easily definable, artistic elements of my practice whilst still acknowledging its more scientific aspects.

Historically the arts and the sciences have been posited as oppositional but this extreme science/ art divide is a particularly English phenomenon, stemming from class-based cultural mores and a strictly partitioned system of education that forces narrower subject specialisation much earlier than elsewhere. The hierarchical struggle observed between these ‘two cultures’ by C.P. Snow (1959) was situated in this context. However, although the arts may be primarily concerned with ’affect’ while science explores ‘effect’, both areas address the same fundamental questions regarding the nature of the world and the behaviour of things in it (Miller 2009). Kincheloe notes,

> “what we refer to as the traditional disciplines in the first decade of the 21st century are anything but fixed, uniform, and monolithic structures…We occupy a scholarly world with faded disciplinary boundary lines.” (Kincheloe, 2001, p.683)

In European countries e.g. Germany these more malleable disciplinary boundaries are reflected in the language. For example 'Wissenschaft', the German equivalent of the word 'science' is a much looser term denoting any systematic body of enquiry. 'Wissen' means knowledge, while 'schaft' has its roots in 'schaffen', meaning to to create, craft or make; so 'wissenschaft' describes a process of 'creating or crafting knowledge'. This more pliable definition is perhaps more sympathetic to my project as both the poetic and technical aspects of my research emanate from the same core.

Appropriate academic models integrating scientific and artistic methods were difficult to find, yet I had to construct a methodology where aesthetic considerations and possibilities for spontaneity through exploratory design practices were not subservient to the quantitative elements of the research. I set forth on an unmapped journey to seek out a suitable methodology inspired by Andre Gide who wrote:

> "Those who count are those who launch themselves into the unknown. One does not discover new lands without agreeing to lose sight, first of all and for a long time, of the shore." (Gide, 1971)

I began to discern my own path: trusting, hoping that experimentation and intuition would yield results.

In textiles design there have been rapid changes in methodology and perspective to incorporate new developments in materials science and embedded technologies. Such design can construct a bridge between beauty and utility, a marriage of aesthetic and function however, earlier PhD theses on the development of technical textiles and textile processes were largely structured using academic models derived from scientific disciplines. This may have been due, in part, to the need to establish the relatively new research-by-project model as a rigorous and valid form of academic enquiry.

Writing in the mid 90's, Sharon Baurley (1997) and Frances Geesin (1995) chose to emphasise their objective development of process and their scientific testing of material properties rather than either their subjective position as designers or the aesthetic, cultural or emotional impact of their work. Geesin states she is taking an artistic point of view with 'a continuing dialogue with science and industry' and although she references many fine art examples of fabric-stiffening techniques, her writing on these and her own practice is almost entirely limited to technical exposition. The artistic aspects of her research became subservient to the scientific, obscuring the creative design elements of the project.

As I was hoping to achieve a balance between the scientific and artistic aspects of my project there was an obvious need for renegotiation of the weighting of these differing approaches. Whilst systematic scientific methodology is efficient when seeking a single, correct solution to a well-defined problem it is less effective when the parameters are indistinct. The designer must therefore employ different strategies.

> "Designing is a process of pattern synthesis, rather than pattern recognition. The solution is not simply lying there among the data, like the dog among the spots in the well known perceptual puzzle; it has to be actively constructed by the designer's own efforts." (Cross 2007, p.24)

Cross argues that while scientists are 'problem-focused' in their approach to a question, elucidating rules and systems of behaviour that eventually lead on to a solution, designers are 'solution-focused', exploring potential solutions at an early stage before the question has been fully framed. This is due, in part to the differing nature of problems that scientist and designers are required to solve. Whereas the parameters of many science problems are clearly delineated, design problems are more ambiguous.

> "What this means is that design is not a search for the optimum solution to the given problem, but that design is exploratory." (Ibid, p.51)

However, in many instances design projects are comprised of differing elements, some weighted towards a scientific 'problem-focused' approach, e.g. developing materials to achieve specific behavioural properties, and others more suited to a 'solution-focused' design approach, e.g. envisaging applications for such materials. In order to encompass this duality in my research I needed to integrate both strategies.

Employing the 'soft logics' of Barnett one can acknowledge the tension between these seemingly oppositional methodologies but recognise their connection as gradated divergence rather than absolute difference. Deleuze and Guattari's pliable conceptualisation of folding and unfolding and of the striated

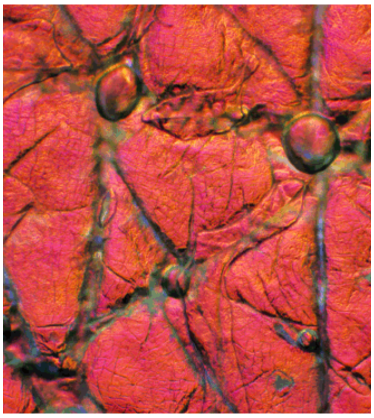


Fig 11. 'Skin Maps' uses light microscope micrographs as inspiration for textile interpretations of the magnified human skin surface. From 'Skin Stories' series 2000-2004, Zane Berzina.

Fig 12. 'Breathing mannequin frame with 3D spring structure', Yasohiro Suzuki. Made from BREATHEAIR tm, a highly elastic monofilament cushioning material that is 95% air (Toyobo Co., Ltd.).

and the smooth imagines continuous and reversible dialogues not separate discrete entities. The term 'striation' is used in the textiles industry to describe a fabric whose slubbed, uneven surface indicates a fault in manufacturing. However, here the word has no such negative connotations, referring instead to divided states of being. Striation is structured, quantifiable, differentiated, partitioned space and being a narrowing of choices, an 'either/or', it could be seen as certain and committed valuing decision over indecision and possibly comparable to scientific approaches. By contrast smooth space is physically continuous, amorphous and undifferentiated, non-quantifiable and open, perhaps analogous to artistic methodologies. However, it is important to recognise that one eventually becomes the other.

> "…smooth space allows itself to be striated, and striated space reimparts a smooth space, with potentially very different values, scope and signs. Perhaps we must say that all progress is made in striated space, but all becoming occurs in smooth space." (Deleuze & Guattari 2004, p.486)

The juxtaposition of both states and continual transformation of one condition to the other enriches the meaning of both. Similarly the integration of quantitative and qualitative approaches can achieve more than either method used in isolation. Spontaneous and intuitive ways of working, where tacit knowledge is of profound importance, are easy to dismiss as invalid and lacking in rigour. However, such approaches used in combination with other methods open up opportunities for innovation missed when only using linear, logically rationalised working practices.

Research paradigms have been evolving to reflect the dual nature of the designer/ technologist and as confidence grows in the validity of research-by-project PhDs more pliable thesis models are emerging. Designer/ researchers are questioning whether academically conservative models are the most valid or reliable and are seeking out flexible structures. Throughout her PhD thesis (2004), Zane Berzina clearly positioned herself as a designer at the heart of the process. She used human skin as metaphor and model at the core of her research, analysing its biological structure and properties as a springboard for the development of novel concepts and technical textiles. She constructed a hybrid methodology, using medical imaging alongside more artistic techniques to develop her textiles, which were displayed in gallery contexts (fig 11).

By exploring personal responses to technical materials artistic methods can clearly communicate material properties to a wider audience than any technical data sheet. This is beautifully illustrated by a group of artists and designers who used the hi-spec materials and fibres of Japanese advanced fibre developers in their work, exhibited at 21_21 Design Sight (2009). The work did not directly convey the technical details of the product but rather the qualities that these properties could bring to objects, revealing the potentialities of materials by revealing the poetic in the scientific (fig 12). These more flexible approaches, examples of which are also emerging in other disciplines such as the social sciences (Richardson 2000) and archaeology (Shanks 2004), offer the opportunity for more creative responses to the research, constructing alternative narratives through methods such as film, illustration, drama and creative writing.

There is a strong subjective element to artistic practice, but this is not necessarily a deficiency, as it would be seen in scientific thinking. As Stefan Collini says;

> "…it has become more widely accepted that different forms of intellectual enquiry quite properly furnish us with a variety of kinds of knowledge and understanding, no one of which constitutes the model to which all the others should seek to conform." (Collini 1993, p.x1vi)

The varied perspectives given by the use of a range of different approaches could be equated with the smooth and striated spaces of Deleuze and Guattari, differentiated and yet connected as a continuous whole.

The symbolic and poetic aspects of my practice were not addressed solely by employing the methodologies of materials scientists and textile technologists to analyse pragmatically data collected from documentation of material behaviours and production processes. Adding qualitative and poetic approaches would illuminate these different perspectives, allowing for investigation of the metaphysical, the emotional and the imaginative alongside the technical. However, in order to have academic validity the experiential knowledge unearthed must have some transferable significance. Subjective approaches can be legitimised through conscious conceptualisation that challenges, analyses and supersedes habitual, conditioned ways of working to find previously hidden meanings that contain a degree of universality. In this approach the process of folding ideas together to develop links and create novel juxtapositions could be seen to have as much significance as any specific outcome.

I needed to employ a range of cross-disciplinary models and methods to create a coherent methodology that would serve the multifaceted nature of my research. Carole Gray (2004, p.21) suggests, "…a characteristic of 'artistic' methodology is a pluralist approach using a multi-method technique." Denzin and Lincoln describe the multi-strand methodologies of qualitative research using metaphors of quilt making and filmmaking: processes of montage that carefully select and order numerous distinct fragments to create new meaning.

> "These interpretive practices involve aesthetic issues, an aesthetics of representation that goes beyond the pragmatic or the practical." (Denzin & Lincoln 2008, p.6)

The term 'bricolage' is used in the social sciences to describe a research approach that combines a variety of empirical and interpretive methods within a single study. The bricoleur operates in the interstices between disciplines, creating conceptual connections and facilitating interactions across disciplinary boundaries.

> "Bricolage does not simply tolerate difference but cultivates it as a spark to researcher creativity." (Kincheloe 2001, p.687)

The interdisciplinarity of the bricolage can act as an agent of change that moves, dissolves or otherwise alters disciplinary boundaries; advancing traditional, single discipline methodologies by amalgamating a range of select approaches. For example, in my own work I have used pragmatic observation, documentation and analysis of material behaviour in production processes in combination with creative film-making and drawing to develop my textile forms, allowing their evaluation from multiple viewpoints (discussed further in chapter 3). The bricolage folds multiple layers of knowledge and discourse together creating novel points of interaction between the researcher and the researched, producing enriched interpretations of the subject of study.

Mette Ramsgard Thomsen's 'Slow furl' textile installation (figs 13 &14) (2008) illustrates how the use of multiple methods can reveal aspects of the project that are otherwise imperceptible or hidden. This large installation comprises a wooden framework supporting an articulated textile skin. Inspired by the action of breathing but slowed to a glacial pace the conductive fabric switches activating motors in the framework when it folds and touches itself. In this way the fabric instigates its own movement. However, the piece moves so slowly it is imperceptible except when photographed or filmed over an extended period of time. Her speeded up films and photographic sequences show dramatic shifts of form that cannot be seen in real time.

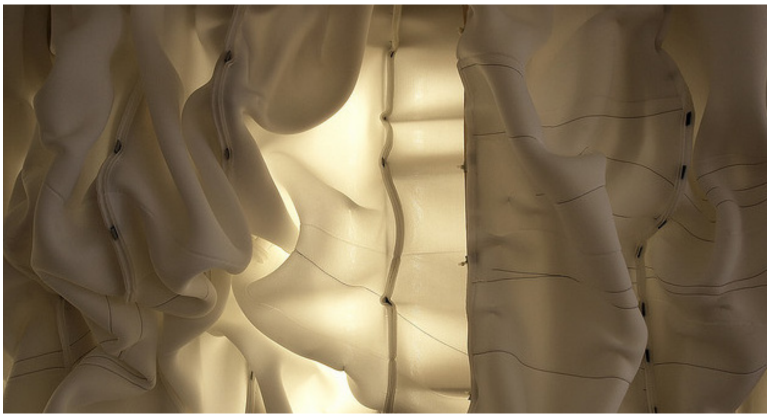


Fig 13. 'Slow Furl', 2008, Mette Ramsgard Thomsen.
Fig 14. 'Slow Furl', 2008, Mette Ramsgard Thomsen.

Despite the possible negative connotations of the word, the bricolage rigorously questions fundamental assumptions about disciplinary mores. Kincheloe says of the bricoleur:

> "As they study the methods of diverse disciplines, they are forced to compare not only methods but also differing epistemologies and social theoretical assumptions. Such diversity frames research orientations as particular socially constructed perspectives – not sacrosanct pathways to the truth." (Ibid, p.686)

The bricoleur is not just 'making do' with what is to hand to bodge an outcome but actively seeking out or constructing tools appropriate to a specific task by combining the best and most relevant aspects of various traditional methodological approaches.

To situate my research I found it necessary to investigate my role as a designer. Am I, the designer, solely a product maker and problem solver, creating functional and commercial products as suggested by people such as Nigel Cross (2007) and Donald Schön (1995), or am I using design to raise questions and to suggest future possibilities? Underlying educational models of textiles design is the assumption that ultimately the outcome will either be functional applied design or non-functional fine art. Critical design, an alternative model originating from product design, dodges such simple categorisation. Removing the designed artefact from its commercial context, critical design is speculative, challenging preconceptions about the purpose and meaning of products in our daily lives (Anthony Dunne 1998). Such design activity operates on the overlapping margins of design and fine art to promote debate in a broad range of areas including design, science and sociology, seemingly retaining its classification as design predominantly due to the intention of its creator.

Some designers exploring the transformative effects of folding have situated themselves in fine-art gallery environments, thereby distancing themselves from the practical considerations of commercial design work while emphasizing the deeper meanings enfolded in their work, thereby "moving across outer, material pleats to inner, animated, spontaneous folds." (Deleuze 2006b, p.14) The transformable garments of both Lucy Orta (Quinn 2003) and C.P. Company (O'Mahony & Braddock 2002) traverse the boundaries between fashion, art and architecture (figs 15-16). Their hybrid clothing/shelters fold and unfold demonstrating an ingenious duality of function that incorporates mobility and flexibility of purpose while simultaneously questioning cultural expectations and the global situation. Such practice benefits from a freedom for experimentation with bodily form and for exploration of underlying concept that would be more difficult to sustain in purely fashion contexts.

I worked for a number of years as a commercial printed textiles designer for fashion markets but as my practice has evolved in a less obviously commercial way my role is no longer so clearly defined. I am distorting volumes and surfaces to invoke an atmosphere as well as physical artefacts with specific behaviours, yet unlike fine art or critical design practice my work is not only a means of self-expression, commentary or critique but also a suggestion of potential future application. I am concerned with the 'affect', that is the bodily experience and sensation experienced through interaction with the artefact as well as the 'effect' or the functionality of the textiles created. Dunne & Raby (2010) say,

> "Critical Design is one of many mutations design is undergoing in an effort to remain relevant to the complex technological, political, economic and social changes we are experiencing at the beginning of the 21c."

The boundaries between art form and functional form are blurring, shifting and dissolving. Art methodologies give the design practitioner licence to explore alternative scenarios that are poetic, non-functional, counter intuitive or even destructive. In synthesizing the openness and freedom of the art brief with the constraint of functionality from the design brief I believe that useful hybrid outcomes are possible. Design that harnesses the potential of artistic inquiry can explore alternative functional and emotional scenarios with transferable application in both fine art and functional design contexts.

The evolution of knowledge through making is enfolded into both designing and the research-by-project PhD structure. Making and meaning are inextricably intertwined. Donald Schön describes the development of design through making as a reflective "conversation with the materials of the situation" (1995, p.78), yet this dynamic dialogue is fleeting and ephemeral. Research-by-project, like archaeology, attempts to preserve and record this unpreservable moment; to re-construct, re-imagine and analyse these activities of life. Through noticing and recording previously unvalued, unobserved or abandoned details of the making process novel critical analysis and theory can emerge. However,

Fig 15. Refuge Wear, Lucy Orta, 1994.
Fig 16. The Transformables, C.P. Company, 2001.

the necessity to observe design practice from a position of distance whilst simultaneously being wholly engaged in the activity presents the designer/ researcher with a fundamental problem. How can I, the maker, when totally absorbed in the often instinctive and intuitive making process concurrently dispassionately observe, note and consider all the knowledge processes, both tacit and explicit, and actions, both conscious and unconscious, that constitute this making? For me, this paradox created a tension between the making and the wider project.

In my experience, the task of documentation threatened to suffocate the creative process. The challenge faced by me ‘the researcher’ (as opposed to me ‘the designer’) to make my embodied, playful and intuitive practices explicit resulted in the loss of the organic spontaneity of my design methods. Although initial samples were freely made with minimal censorship, the time consuming effort to frame and conceptualise process and outcome prevented further developments being made in a timely manner. I needed to fold theory and practice together to achieve “a correspondence and even a communication between the two levels, between the two labyrinths, between the pleats of matter and the folds in the soul.” (Deleuze 2006b, p.4).

To bring both balance and rigor to my research I had to devise straightforward methodical systems to record the pragmatic and the phenomenological aspects of the research. To capture the practical details of substrate construction I devised a form that evolved over time to optimise its simple integration into the making process: this eventually metamorphosized into a searchable database (appendix/ DVD). To address the more ephemeral aspects of the process I carried out a series of free and generative writing exercises and later in the project I began to make both audio and video recordings of some of the making activities. This multi-method approach is discussed further in chapter 3.

In order to study the textiles at the core of the research it is necessary not only to scrutinize the complex and embodied making process but also to examine the outcomes from a point of separation and distance. Such an enquiry must also take account of the various philosophical and cultural conventions that have influenced the research design. In my experience of the research process, the central question is constantly shifting and evolving relative to the approach dominant at any given moment. Echoing physical and conceptual folding, the project metamorphosizes and adapts. There are changes of direction and shifting relationships between concepts over time as I twist and fold the structure of the research. However, I have found using a bricolage of methods allows for dynamic, multi-perspectival analysis of this constantly evolving research problem.

Refraction of core themes through different media can alter their appearance, assisting recognition and consideration of diverse and sometimes conflicting viewpoints and potentially generating new thinking. Through the use of diverse methods the project can be deconstructed into multiple constituent parts, new links and connections being forged by refolding the material together in fresh arrangements (discussed further in chapter 3). In a process influenced by Deleuze's concepts of folding, ideas are pleated in on themselves in a unification of conceptual exteriority and interiority. In Deleuzian folding ones own thoughts become enfolded with those of another, juxtaposing hitherto unrelated ideas and generating new meaning as a result of this unexpected relationship. This folded thinking is a process of pliable and dynamic transformation and could be seen as a reversal of the prioritisation of logical rationalisation over intuition. Pennina Barnett describes it as,

> "…a form of experimentation: an essentially creative and critical activity, activated when the mind is 'provoked by an encounter with the unknown or the unfamiliar…' " (Barnett, 1999, p.26)

Such conceptual folding is a search for the re-contextualisation of meaning rather than for absolute truth. While folds separate and isolate areas both physically and conceptually an infinite potential for constant refolding allows for future renegotiation of these relationships. This creates "a topology by which inner and outer spaces are in contact with each other" (Conley 2005, p.113). Thus, subjectivity, affectivity and materiality are connected and intertwined: physical, temporal and conceptual worlds are not separate but continuous, although differentiated by folding.

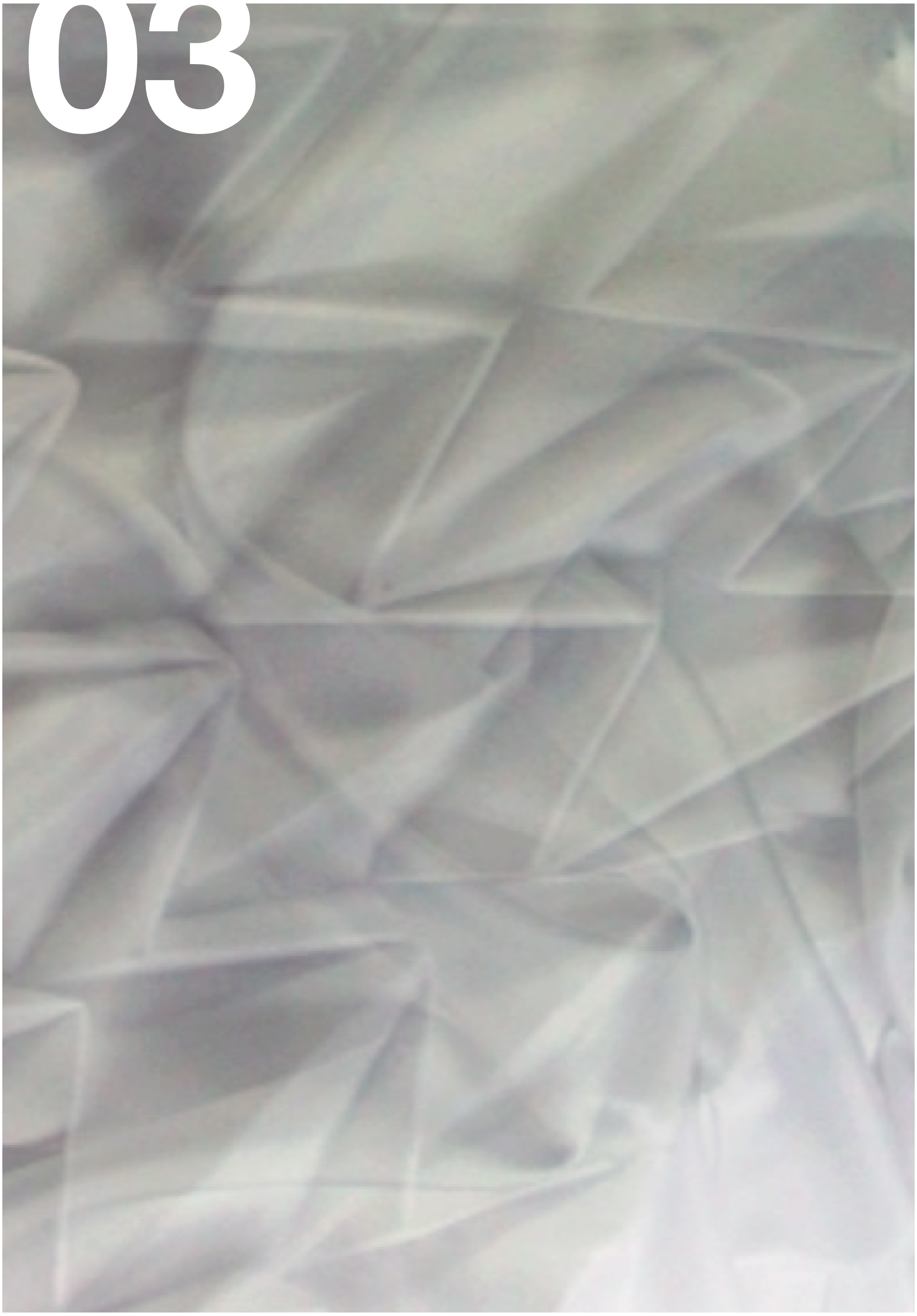
> "The division of the continuous must not be taken as of sand dividing into grains, but as that of a sheet of paper or of a tunic in folds, in such a way that an infinite number of folds can be produced, some smaller than others, but without the body ever dissolving into points or minima." (Michel Serres quoted in Deleuze 2006b, p.6)

By highlighting the essential connectivity of all things, which allows seemingly oppositional or divided states to exist simultaneously yet without contradiction this conceptual approach folds together diverse modes of being, thinking and representation to make coherent and continuous meaning.

In this research the fold or pleat has provided a point of focus for the generation of both new process and new thought. While tangible folds may have been the catalyst for physical and theoretical evolution it is dynamic thought that has endeavoured to actively fold materiality and concept together into a cohesive whole more profound than the surface appearance of the physical fold. I have sought to create coherence through the hermeneutic synthesis of images, texts and data to rework disparate and refracted viewpoints into a unified and cohesive whole.

This chapter has considered how the principles of folding, biological modelling and pattern have all been instrumental in shaping the 3-D textile outputs of the research and has outlined my use of a ‘bricolage’ of methods to explore fully the different aspects and perspectives presented by the situation of my research at the boundary of art, design and science; an approach supported by philosophical discourse on folding that emphasises connectivity and flexibility.

CHAPTER 03



Chapter 3: Playful practice in constraining creases

This chapter compares the differing opportunities and challenges presented by playful, unbounded approaches to the research and more constrained, delineated methods to see which might best support the development of the project. It then describes the range of methods used to develop the practical outputs of the project, discussing how these have been organised to provide a generative structure for new work.

Play and constraint

> "Humanity has advanced, when it has advanced, not because it has been sober, responsible and cautious, but because it has been playful, rebellious and immature." (Robbins 1980, p.19)

Play can be a process of exploration and explication as well as a means of individual expression. Using ludic research methods for practical production allows one to work in a way that is spontaneous and without pre-meditated purpose. It offers opportunities to break out of linear patterns of thought and established ways of working ingrained by institutional education and years of professional practice. The purposeful purposelessness of play cultivates a very particular mind state in which one is relaxed enough to relinquish control and allow the unknown to occur. By being immersed in the moment, totally absorbed by the task in hand and acting through intuition not intellect, one not only finds fulfilment (Csikszentmihalyi 1991) but also allows space for innovation.

But how is it possible to preserve this precious playfulness within institutional constraints that often prioritise intellectualised, rationalised and well-documented methodologies? The process of negotiating today's audited education system with its measurable outcomes can have a deadening effect when, as Jung points out,

> "The creation of something new is not accomplished by the intellect but by the play instinct acting from inner necessity. The creative mind plays with the object it loves" (Jung 1986)

Mary Schoeser's (2008) butterfly illustrates the problem of explicating creative inspiration. This metaphorical butterfly remains in your peripheral vision fluttering around your shoulder, disappearing the instant you attempt to scrutinize it closely. The nature of PhD research forces you to focus on the butterfly, meaning methods must be devised that enable this with the least disruption. My own struggles with the obligation to record my practice have been discussed in chapter 2 and ultimately I found it necessary to construct multiple archives to encompass the multiple methods, perspectives and potentialities of the project. However, the confines of a structured methodology can actually prove more liberating than an entirely free approach.

A fine balance must be struck between bounded and unbounded play. Too narrow or too broad a focus both stifle ideas. My early research approach, contrary to my pre-PhD playful and improvisational practice, was very cautious and controlled in an over-zealous attempt to be ‘scholarly’.

> “…we often have this a priori sense that when you have fun its not serious – it has to be bleak to be serious.” (Darrieussecq & Dillon 2008, p.10)

An overpowering desire to do ‘proper’ research meant I restricted my methods of exploration, emphasising pragmatic verbal description and controlled material experiments. The playful and artistic elements of the project fell victim to my potent self-censorship until it became apparent that such overly restrictive constraint deadened this iterative voyage of discovery. One’s mind and methods must be open in order to discover the original knowledge necessary for the PhD, a mind state perfectly exemplified by Dr Mary Malone in Pullman (2005, p.226)

> “She wasn’t sure what she wanted to do, except that she knew that if she fooled around for long enough, without fretting, or nagging herself, she’d find out.”

Yet while I could recognize that I have an innate need for playful interaction with materials and processes to gain the insight necessary to evolve novel outcomes I found it extremely difficult to give myself permission to ‘fool around’ without ‘fretting or nagging’ myself and thereby effectively curbed my essential forays into the unknown territories.

In my experience totally unbounded play can also create anxiety and block creativity. At the beginning of my research, where rules and boundaries were not yet recognised or clearly delineated, such overwhelming freedom left me not knowing where to start. Graves (2003) notes,

> “when designers work to a brief, the constraints of that brief, including the technical restrictions, are often the impetus which stimulates their best creative efforts”

For me, the identification of institutional, material and self-imposed margins provided a scaffold that fostered creative production. By working within set boundaries I could illustrate how a defined theme or method lent itself to a variety of interpretations and outcomes. This is exemplified by my use of the thematic photographic series, discussed in detail below.

My work has been formed within a framework of physical material constraints. However, recommended modes of production are more pliable and have been twisted, contorted and manipulated to suit my own ends. Established rules are frequently transgressed through playful exploration. Such transgressions are sometimes seen as subversive. Note the uneasiness in older generations conjured by the truncated language of texting. However through these playful manipulations youth takes ownership of language, clarifying concepts and mastering anxieties (Rosen 2008). I believe designers' playful interaction with materials serve an equivalent function. Through play the designer takes ownership of the material and control of the design situation.

The excitement of play is generated through risk taking, breaking free from externally imposed order and transgressing established rules. Yet under such unregulated conditions the potential for disaster is high. In my early practice I found it difficult to trust that novelty and innovation would emerge from my loosely directed creativity. Full of anxiety I attempted to mitigate the risks of failure by second guessing the final outcome, narrowing my focus without due consideration for the interim processes of development. However in striving to alight too early on a concrete application for my textiles I disempowered my creativity, dampening my artistic expression.

In order for play to lead to innovation it is necessary to remove the fear of failure, seeing mistakes as springboards for new iterations of the work.

> "Mistakes are, after all, the foundations of truth, and if a man does not know what a thing is, it is at least an increase in knowledge if he knows what it is not." (Jung 1959)

Drawing on my experience of the Alexander Technique I attempted to overcome my aversion to uncertainty. The technique challenges habitual tendencies to focus on outcomes of actions, referred to as 'end-gaming', rather than on the action or 'means whereby' (Gelb 2004). Students are encouraged to live in the present moment, concentrating on 'how' rather than 'what.' Cultivating this approach promoted recognition of the value of interim steps. I became more at ease with allowing the practice to develop freely, drifting from order into chaos followed by the re-imposition of order. I became more accepting of ambiguity and vagueness, privileging unintended effects where appropriate, allowing them to supersede original intentions and embracing error as part the progression of the work. A concrete example of this approach is given by my efforts to devise a new folding pattern based on a double sink fold (discussed in detail in chapter 6). Even after careful construction of paper models in the first textile attempt, ❖ sample 82 (fig 107: ★ film 1), I omitted a cut line that meant I had to improvise the folded form. I eventually made ❖ sample 105 to the original 'new' pattern but due to my error now benefited from two novel forms with two distinct behaviours. This more relaxed and playful approach allowed the work to blossom into a series of open suggestions for future use rather than a constrained selection of precisely specified functional outcomes.

Playfully blending canons of process in a collage or 'bricolage' of methods (previously discussed in chapter 2), having to improvise alternative methods due to lack of skill or equipment and being ignorant of or ignoring established rules of production can all produce innovation that advances practice. Distance gifted by non-doing can also impart novel perspectives. Periods away from the research gave time for absent-minded reflection and became part of my creative process. The mind when distracted from intense focus on the project by other preoccupations can find space to play subconsciously with the material. On reapplication to the research initial disorientation gradually gives way to a greater degree of clarity as the work pulls into an alternative focus. Baudelaire describes this reappraisal of the world, referencing the convalescent who is,

> "rapturously breathing in all the odours and essences of life; as he has been on the brink of total oblivion, he remembers, and fervently desires to remember, everything." (Baudelaire 1863)

He asserts that this state of heightened sensation is very similar in effect to the attitude held by children, where great pleasure is taken in the consistent novelty of the world, and also that of artists, who produce work employing 'childhood recovered at will' with an insatiable enthusiasm and attention to detail giving both observational and expressive power.

A leave-of-absence gave me time out from the formal structure of PhD study. This allowed me to free the practice from the tyranny of documentation and give myself permission to prioritize more creative research activities that had been hitherto avoided. The rejuvenating power of play seeped into the work. I was able to set aside theory and approach the practice light-heartedly. Under no pressure to determine concrete applications for the materials and forms produced I was afforded an opportunity to make without any sense obligation. Significant progress was made with this approach, resulting in a shift of emphasis in the project from outcome to exploration. This generated a whole new perception of the possibilities of both the textiles created and of the process of making.

The journey to a taxonomic tool

> "The most perfect and vivid expression of our time, in philosophy as well as in literature and art, is the fragment. The great works of our time are not compact blocks, but rather totalities of fragments, constructions always in motion by the same law of complimentary opposition that rules the particles in physics…" (Octavio Paz quoted in Berger & Christie 1999).

PhD research requires the generation, gathering and most significantly, the organisation of multiple sources and formats of material to construct the project: disparate fragments that must be given collective coherence.

Fig 17. Origami washing line and postcards on wall.

Many creative projects begin with the collection and production of individual elements, raw material from which original concepts and artefacts can be composed. In my case this playful compilation of fragments have included still and moving images, texts, samples, objects, and an eclectic mix of materials collected from external sources as well as self-generated through studio practice and its documentation (fig 17). Ward (2008) notes the prevalence of designers using vision as the primary means of interaction with what he terms their 'reflective washing lines' or miscellany, but researchers must delve deeper to find more than purely visual connections.

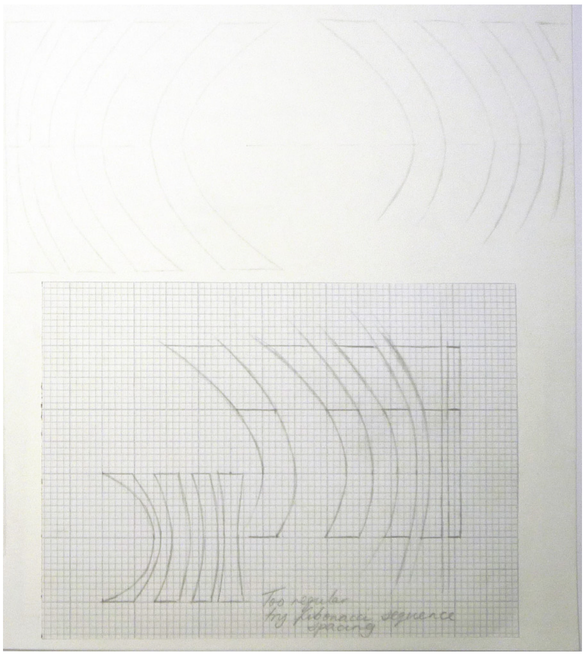
> "The image of the washing line is used as a connective device, a metaphoric as well as 'real' line stringing together reminiscences and ruminations in a flow of imaginative investigation." (Goett 2005)

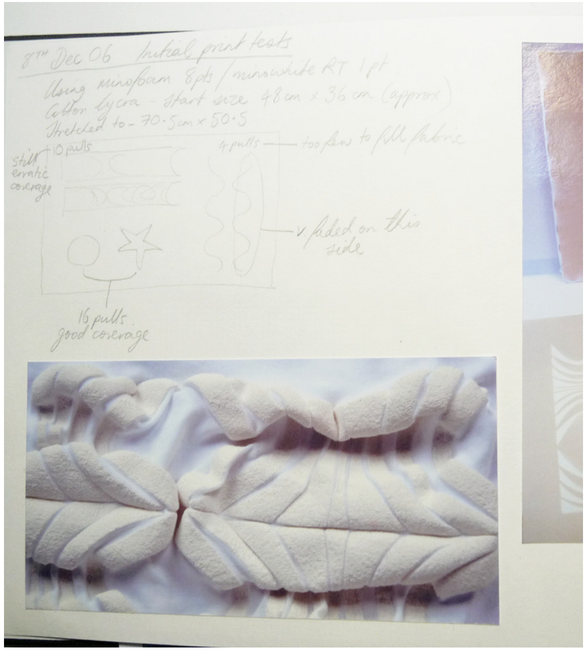
The process of selection within the assemblage is crucial for setting the foundations of the project, imposing a degree of order even though the significance of each component chosen or grouping made might not be apparent at the outset of this enterprise. The inclusion of both visual and verbal elements enables the encapsulation of multiple aspects and perspectives within a single study. However, while it's easy to collect, it's harder to connect. In the words of Edmund de Waal (2009), "It is not enough to cut it out. One must sew it together again." Collections require the deconstruction and reassembly of their contents to make meaning that takes them beyond merely being cabinets of curiosities (Goett 2008). In creative practice this reassembly often involves the playful manipulation of incongruent parts of the collection.

My research employed a number of creative practices to generate, analyse, evaluate and reconfigure the collected components of the project but initially restricted their scope predominantly to pragmatic production, description and documentation of practice. Despite this overly constrained approach the outcomes of these methods of documentation revealed unforeseen poetic aspects. Thus playful approaches re-surfaced, albeit in an unpremeditated fashion, highlighting the potential symbiosis between play and constraint.

I started observing the fold in natural forms, completing sequential drawings showing the opening of flowers, crinkled coral and wood thinking they might provide inspiration for the development of biomimetic or biomorphic folded structures. These drawings were intended to give an accurate two-dimensional representation of a physical and three-dimensional world and were a way of analysing the fold. The use of visual thinking for analysis and conceptualisation cultivates different perspectives than those developed through verbal syntax. Visual rather than verbal exploration unearthed different types knowledge e.g. the micro and macro folding evident in the packing and deployment of gladioli flowers (fig 18) (biomimetic inspirations for the development of form discussed previously in chapter 2). This

Fig 18. Gladioli flowers opening. Pencil on paper.





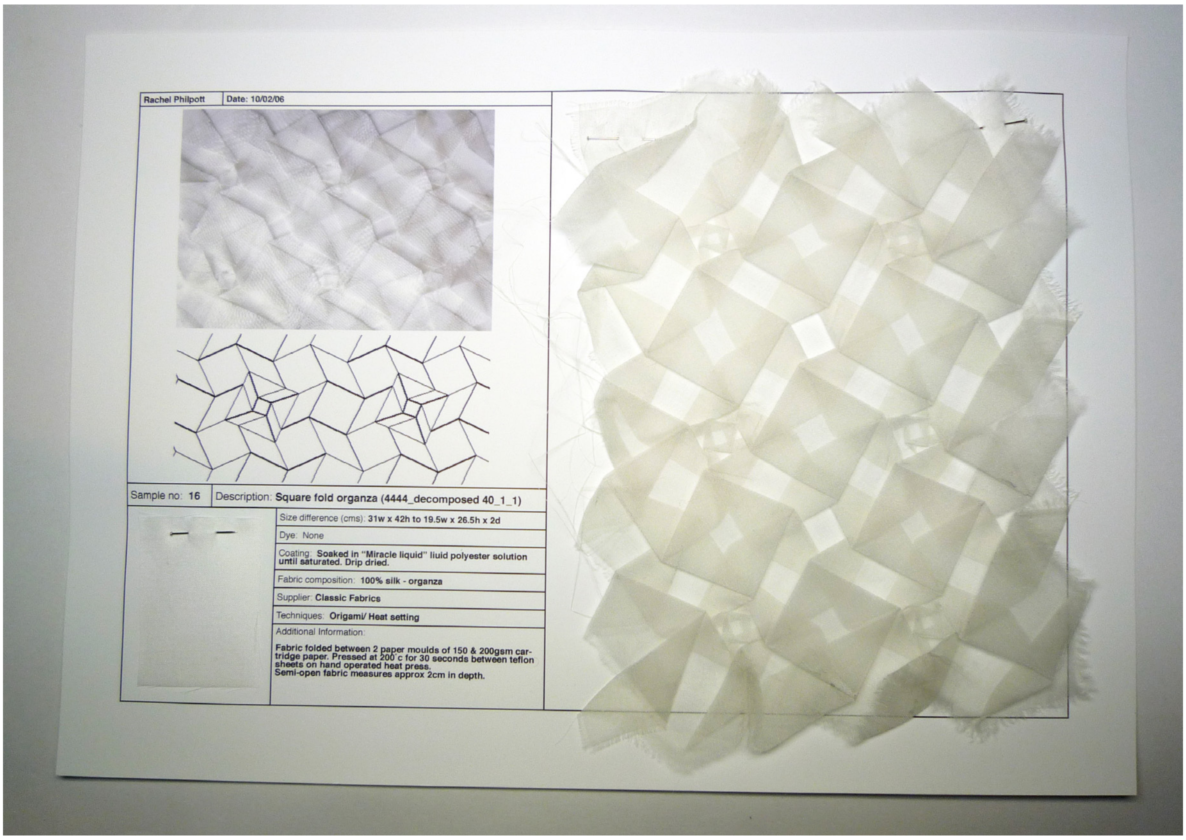
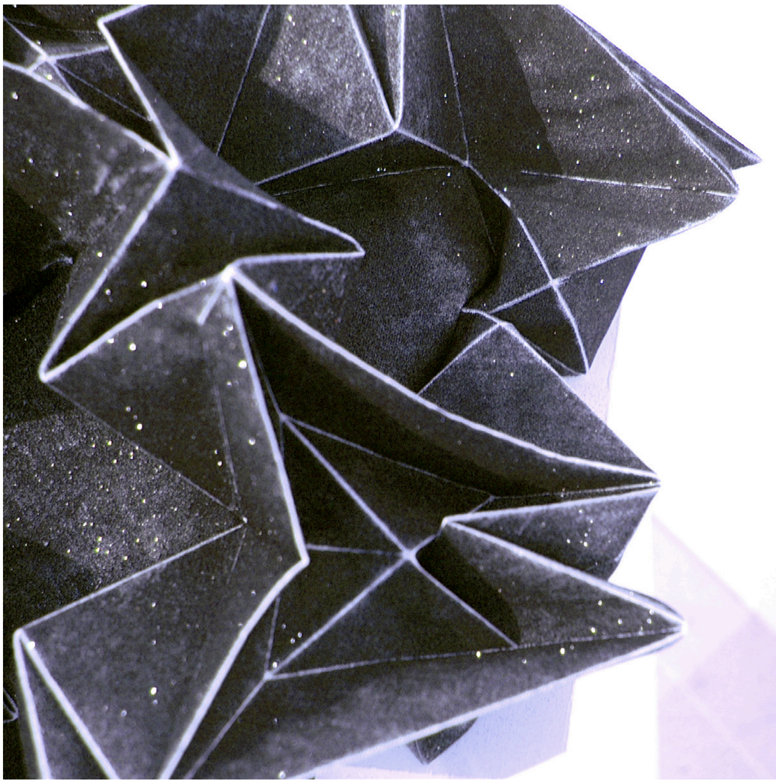
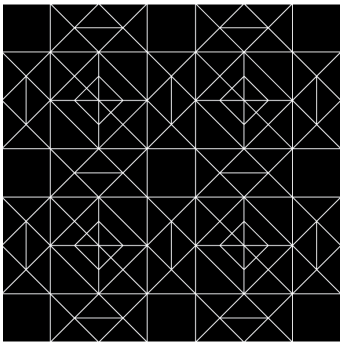


Fig 19. Sketchbook page, sketching out design for printing. (top left)
Fig 20. Sketchbook page, printing notes and photographs documenting process. (top right)
Fig 21. Sample record card. (bottom)

Sample | Base materials | Print materials | Coating | Application

Sample no. 039 **Sample name** Black Glitter Permastiff





Date 10/12/2007

Base Material ID	JL1002
Material start size	125h x 95w
Material finished size	60h x 30w x 27d
Material stretched size	-
Print material	Minofoam(12pts), Magnaprint binder(3pts), Minoprint Black(1tsp): ....
Coating	Black 36P 008 Hex x 001Glitter
Techniques used	○ Stitch ◉ Silk-screen ◉ Origami ○ Laminate ◉ Heat set ○ Mould ○ Transfer Print ○ Bond ○ Laser cut ◉ Other…
Production description	Puff binder silk-screen printed (6 pulls). Left to dry. Adhesive silk-screen printed (6 pulls). Glitter sprinkled over while adhesive still wet. Left to dry overnight.
Finishing process	Baked @ 140°c for 5 mins. Ironed to fold into final shape
Positive outcomes & observations	Fabric holds shape well and glitter gives and interesting surface texture.
Problems encountered	Uneven coverage given by adhesive silk-screen print. Glitter prone to drop when rubbed.
Future amendments	

Fig 22. Example of electronic database entry.

practice of thinking through looking marked the beginning of my categorisation of different fold types, a process in which verbal and visual practices worked together to enable organisation of the material.

The evolution of these categories continued as documentation of process and outcomes progressed. In my writing I recorded factual findings. Sketches, diagrams and written notes were completed parallel to the studio practice to capture basic information relating to the process of making (fig 19). These notes were followed by written evaluation of the results including amendments to be made in future iterations, which aided digestion of the data. I also photographed different stages of the process as well as creating numerous images documenting each sample created (fig 20). This gave a solid base for cataloguing samples.

Categorisation is a way of imposing order through comparison, encouraging detailed analysis of how individual elements conform or deviate from clearly delineated constraints. Pragmatically, categorisation gives an overall structure and coherence to the collection and ensures essential data is not lost. However, the taxonomy of material is a creative generative exercise, an active process of concept development that allows the identification of generic elements through the recognition of similarity and difference. The taxonomy is a constantly evolving entity, an organisational structure continually in flux, vulnerable to change and reclassification as information and objects are encountered that do not conform to existing categories. While designation of distinct categories provides foundations from which to build these must be malleable enough to extend or mutate as the material develops. I find unclassifiable, boundary jumping entities those from which there is the most to learn. They challenge existing structures and conceptions, forcing reassessment that advances the work.

I constructed databases to record the process and outcomes of making as well as raw materials used. Initially this database took the form of physical record cards that combined text and textile (fig 21). Categories included were influenced by practice presented in theses such as Baurley (1997) and Geesin (1995). The final format was modelled on sample displays at the ‘Well Fashioned: Eco style in the UK’ exhibition (2006) which I adapted to my own requirements. This physical record provided a backbone to the practice, continuing in an amended, streamlined format as the research progressed.

As the number of samples increased I constructed a central searchable digital database combining photographs and text (fig 22: also in PDF format on accompanying DVD). This linked to a parallel database that categorised substrates used, facilitating quick identification of suitable processes and materials for future samples. However, although the digitised information is more easily and more widely accessible it is not a substitute for its physical counterpart. While the text is unaffected by its conversion, the transformation of textile into pixel limits access to important information such as scale, exact colour or tactile and behavioural properties.

Video documentation of production made the methods of making explicit and emphasised process rather than outcome (★ films 1 & 2). These recordings, a technique of knowledge elicitation, captured information unnoticed at the time of making. For example, the films highlight the repeated minute easings and adjustments I make to the materials with my hands. This constant but unconscious motion could be described as an example of tacit knowledge in action, essential and integral to my textile practice yet unregistered on an intellectual level at the time of making.

Video and audio recording also promote reflection in action, a positive example of documentation of process altering the activity. Consciously and audibly discussing the making with oneself as the process progresses encourages elaboration of the rapid succession of ideas that surface throughout the practice. To have these contemplations captured fosters deeper reflection as the pressure to remember them all is removed; these reflective conversations can be revisited and reconsidered at a later date (see Appendix 2). In this procedure practice and theory become seamlessly enfolded, evolving simultaneously.

Reviewing these documentaries of process one is able to stand outside the activity and observe oneself in the third person. This adoption of a detached and critical view goes beyond the initial subjectively remembered narrative to enable close analysis of the practice. Using such ethnographic techniques to verify one's own activity mitigates the pitfalls of relying on inaccurate 'composite' memory that fold in on itself to construct fictive narratives from imperfectly recalled fragments.

Video recording can reveal both pragmatic and poetic aspects of the practice. Films, like the outcomes of the practice, rarely reflect the image in your minds eye but these disparities can prompt tangential thinking. In ★ film 1 on one level I find it disappointing that you can barely see the clear polypropylene

Fig 23. Phantom, Alison Watt, 2007. Oil on canvas, 213.4 x 335.3cm.
Fig 24. Photographic spot series, my fabric folds – Running stitch manipulation on polyester, sample 3.

as it spreads across the substrate. However, its invisible march across the landscape of the polyester strikes me as a wonderful analogy for the endless amount of invisible work that goes into producing the pieces. As creativity creeps into pragmatic practice visual thinking and the use metaphor become transformative tools.

As my practice expanded concepts evolved through verbal, visual and tactile exploration, giving a rounded understanding of the nature of folding not possible through any single method. New perspectives emerged as 2-D image became 3-D object, re-interpreted once more as 2-D representation. Drawing, writing, photographing and videoing the practice became an act of creative translation and contemplation. Individual methods combined to become a multilayered narrative of the whole, a complex process full of twists, self-references and reflections folding one over another. Using this range of activities enabled me to view the project from different standpoints and engaged my whole body in the process of thinking, a kinaesthetic generation of knowledge. Methods initially dismissed as not serious were realised to have significant value for the exploration of both form and concept, new potentials for their imaginative application were seen.

A visit to Alison Watt's 'Phantom' exhibition (2008) proved to be a powerful catalyst for my work (fig 23). Her artistic interpretation of folded cloth highlighted the potential of abstraction to stimulate imaginative meanderings that lead to novel concepts. The monumental scale of her works enfolds the viewer. The paintings are extremely stylised occupying a liminal world between figurative and abstract yet still strongly reference the body. Pictures of movement but devoid of movement, appearing as if painted from marble or plaster sculpture the forms seem static, frozen. From fabric but beyond fabric, the smooth surfaces are devoid of any of the texture of the original cloth. Instead slight traces of textured paint disrupt the flat surface, vestiges of process that evidence amendments, reminiscent of scars left by folding in my own work.

Providing creative inspiration, Watt's paintings re-awakened a compelling desire to produce image for purposes above and beyond documentation. Her work, strongly thematic and unified by style of presentation triggered my development of a series of small, loosely bounded creative exercises that focused my investigation while still allowing a broadness of scope. These constraints gave comprehensible structure to what had hitherto appeared formless and endless, enabling me to focus on the processes of production rather than 'end gaming'.

The first of these exercises was a series of photos, thematically united by the fold and clearly connected by the format of presentation: visual explorations bounded by their frames but components of a potentially infinite series (fig 24). Here photography was not employed primarily as a tool of documentation and recording, but as a tool for creation. Not only capturing a frozen moment in time, an image, but capturing a becoming, a conceptual process. Things lie behind the surface of the photograph, not immediately apparent they must be searched for. In an attempt to break away from habitual readings of the pictures, to make the familiar strange I abstracted the image by using close-up as well as by allowing adjustment of the objects' original orientation in the framing of the picture. I avoided standard 'A' size paper formats for presentation as I felt this restricted the image to a single viewpoint. A square design still limited the viewing of the print to one of eight possible angles. The circular frame ultimately proved to be most effective, encouraging viewing of the image from any position.

From the primary loose thematic boundary sprung new and tighter categories as images were evaluated and compared. An investigation of different types of folds with contrasting properties and behaviours resulted in the categorisation of a number of distinct folding types. Collections of 'Natural' and 'Man-made' folds were collated from a number of walks and the observation of my domestic environment (figs 25 & 26). A series of photographs of sculpted drapery elicited the category of 'false folds' (fig 27), immobile folds carved from intransigent materials that possess only the appearance of pliability and dynamism. These groupings arranging like with like began to describe a branching system of classification, a ranked hierarchy in which main classes divided and subdivided. Verbally conceptualised categories such as 'controlled' and 'uncontrolled' or 'hard' and 'soft' folds emerged from visual taxonomies, intertwining theory and practice.

Juxtaposition of pictures from different categories led to an investigation of the extent to which the properties of these disparate folding types could be controlled and cross-pollinated in my textile practice to create infinitely variable forms.

Fig 25. Photographic spot series, natural folds – Leaf.
Fig 26. Photographic spot series, man-made folds – Pewter vase, Toby Russell, 1998. V&A museum, London.
Fig 27. Photographic spot series, false folds – Marble sculpture 'Maternal Affection', Hodges-Baily, 1837. V&A museum, London.

> "…forms that can change, morph and move: a new category of objects defined not by what they are, but by the way they change and by the laws that describe their continuous variations" (Carpo 2004, pp.14-15)

Montage of images depicting my own samples and a variety of folded objects and materials prompted re-evaluation of samples created as well as the conceptual framing of the project.

Individual elements in the collection become dislocated from their original contexts. Removed from familiar frames of reference juxtaposed against seemingly unrelated items new associations take place. This is exemplified perfectly by Benjamin's textual 'constellations' of The Arcades Project (1999). His montage of traces, debris and fragments constructs a unique conceptual network, a collage of the incomplete where extraordinary meaning is found in the ordinary. The montage has the power to create conceptual disruptions, forcing new thinking (Adorno 1997, pp.155-156). This method of combining disparate verbal and visual material is used throughout the research, evident in film edits, concertina books, the writing 'cut and paste'. These collages question the relationship of individual parts within the whole and can be a means by which to reunify or synthesize the disparate elements into new creations, echoing the methodologies of 'bricolage' discussed previously in chapter 2.

Hirschhorn highlights the subversive nature of creating unexpected juxtapositions.

> " Doing Collages means creating a New World with elements of the Existing World. Doing Collages is expressing Agreements with the Existing World without approving it. This is Resistance.
>
> Doing Collages is based on this Agreement and this Non-Approval. That is the reason why often Collages are not taken seriously. That is the reason why making Collages is suspicious and why doing Collages is considered unprofessional. But those are precisely the arguments which demonstrate the Resistance of the medium Collages. Collages resist Facts, Collages resist Information and Collages resist Documents. Collages create a Truth of their own." (Hirschhorn 2008, p.40)

New meanings are created by our innate drive to make sense from non-coherence but these meanings are liable to shift over time. Contexts change, perceptions of both maker and user of the collection are liable to alter as different connections and juxtapositions emerge.

For this reason I find myself reluctant to tie material down in a traditional sketchbook format where images lie forever alongside their neighbours, preferring an arrangement that facilitates the concurrent contemplation of multiple images. I favour the flexibility of sketch boxes, un-mounted collections of photocopies, printouts and drawings that can be readily rearranged to create diverse constellations of connections. These dynamic images can migrate freely from one categorisation to another, their

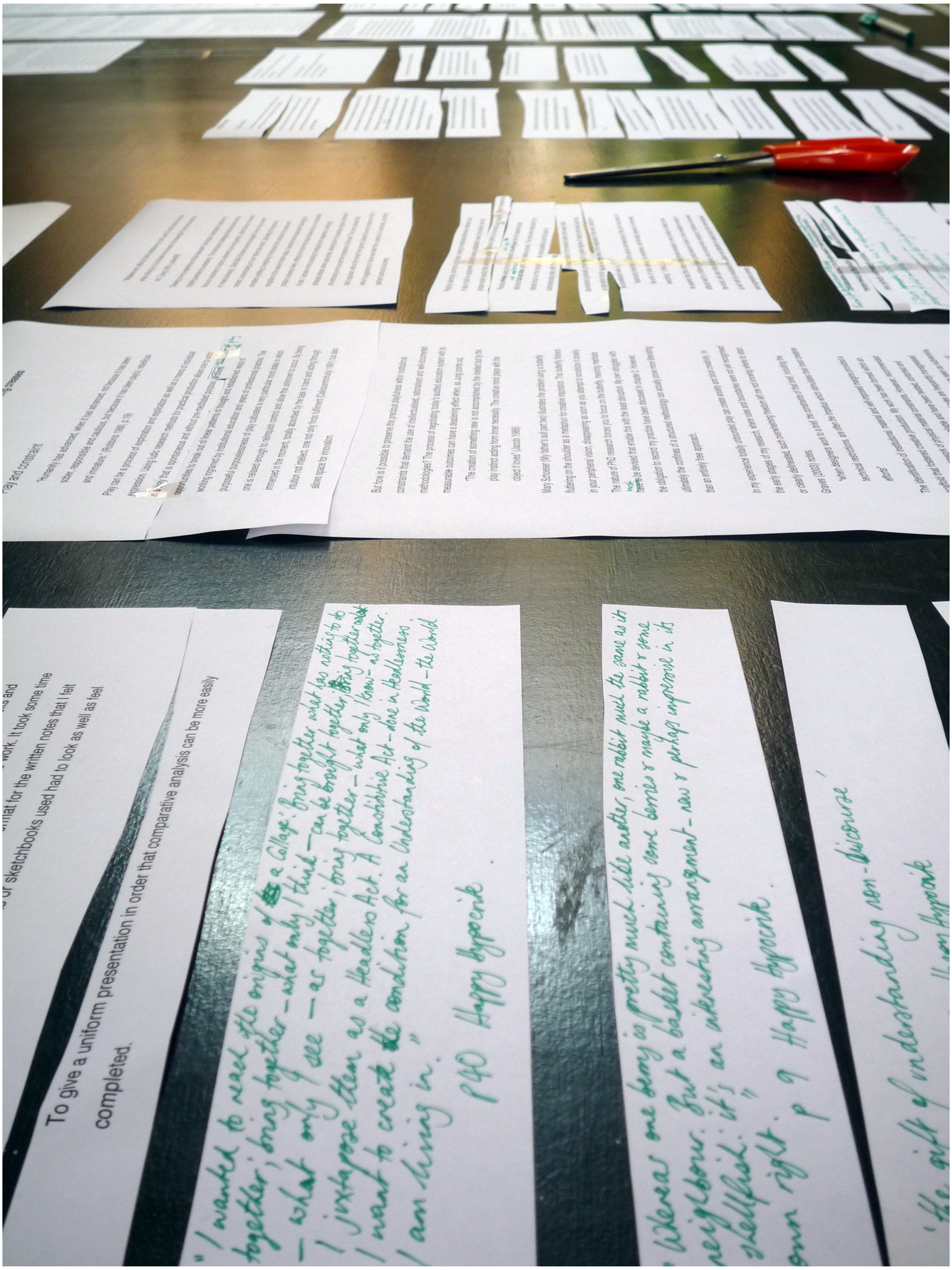


Fig 28. Writing 'cut and paste'.

mobility continually producing new juxtapositions and previously unexplored possibilities. I fear that to fix their relational order permanently would deaden them as surely as a pin through a butterfly.

I often resort to physical printouts of digitised information, as it is impossible to view numerous documents simultaneously on screen. This need for a visual overview extends to my written practice. My writing is a complicated jigsaw puzzle. Small clusters of information must be teased into a coherent narrative through successive iterations of organisation. Unable to carry out major revisions in the pixelated world of the word processor this reorganisation is a physical cut and paste with scissors and Sellotape taken to computer printouts of the writing (fig 28). The writing becomes a physical object, its form in flux, a textual collage testing concept; amended, cut up and taped back together. Several reorganisations of material take place before a clear narrative emerges. Only after writing has progressed through this physical organisational process can it be reconstituted to efficiently disseminate ideas, approaches and findings of the research to a wider audience.

Presenting my research at exhibitions, conferences and in print has formed part of the research process, stimulating the creation of work that could communicate the essence of the project clearly to the public. This offers a chance to reflect upon the core themes of the research as well as to consider the most appropriate modes for its dissemination.

Standard technologies of communication e.g. PowerPoint could be accused of being devoid of gesture, spontaneity and interactivity but they are useful. The combination of text and image in the PowerPoint format can assist the construction of clear narrative.

The exhibition environment provides its own challenges, framing the work both visually and conceptually. Choices made regarding presentation influence how work will be read by the audience, and dialogues arising from viewers' responses to the practice can shape future research. Situated in a 'white cube' gallery the research is placed in an art context. The presentation of textiles in gallery settings dislocates them from their more usual milieu in use and in motion on bodies and in space. The constraints of the gallery can mute the work, the stasis of the exhibits and the 'don't touch' etiquette in opposition to fabric's mobile and tactile existence. However, this contextualisation can surface previously concealed aspects of the project.

Video was for me a key method for the dissemination of my work. Initial films (★ films 2 - 4) were made primarily to show aspects of the production process and the samples in motion, mobility being a key component of the work difficult to demonstrate within the constraints of the gallery or lecture hall. However each subsequent iteration of the film progressed further into abstraction, assisted by my expanding knowledge of filming and editing processes.

The inherent contradiction of using video, essentially coloured light, to depict tactile surface was turned to my advantage. Obscuring the tactile transformed my relationship to the textile, creating alternative frames of reference that unleashed imagination. The videos now not only captured the dynamism of the folded structures but also intentionally abstracted their physical form to encourage a re-conceptualisation of the object, its scale, its shape, its material. This moulded the next iteration of the physical form in a cyclical process, the re-design of physical space occurring through oscillation between physicality and immateriality, a journey from 3-D to 2-D and back again.

In ★ film 5 a very tight focus was used as a deliberate device to make scale ambiguous, freeing the imagination to perceive the object from new perspectives. Various filters and effects were applied in an attempt to abstract the object to a degree that moved the image beyond the actual and into the realm of the conceptual. Using these methods enable the depiction of fictive future folds, an example of my practice generating theory. The overlaying of images although originally undertaken purely as an artistic device suggested future development of work as dual-layer structures that could either be separate but conformable, joining in a 3-D folded tessellation, or bonded at strategic points. Such developments could increase possibilities for multi-functionality, like two-faced fabrics that demonstrate complimentary properties.

I intended my next film (★ film 6) to be on an architectural scale, giving the viewer the feeling of inhabiting a dynamic folded environment. To achieve this I projected the image, liberating me from size constraints presented by a TV monitor. However, concept and working methods had to be modified to fit the external constraints of the exhibition space. Health and safety restrictions prevented me realising my vision of a wall projection that incorporated the work in motion as part of the architecture of the building, forcing creative solutions. A renegotiation of the design took place in which the film took on the circular frame of the photographic prints to make it suitable for the situation of the projection and to provide

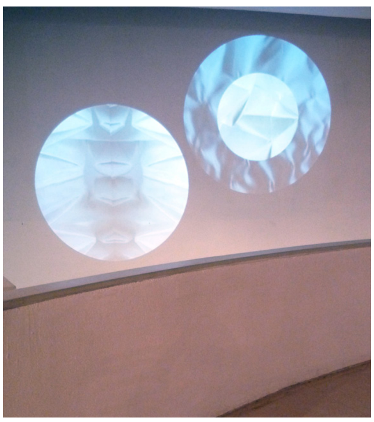


Fig 29. Photomontage exhibited at 'Work in Progress', 2009.
Fig 30. Film projection exhibited at 'Work in Progress', 2009.

Fig 31. Fictional fold drawing, 2009.

a strong visual link between the video and the wall piece exhibited nearby (fig 29 & 30). Although the circular framing changed the atmosphere conjured by the work, this literal reframing provided a different perspective that highlighted other aspects of the project.

As designs being developed are speculative, the use of visualisations using hand drawn and computer generated image, film and animation are important in order to evolve concepts and to communicate ideas. Using video I was able to give very rough and ready models the appearance of resolution, shooting both paper and fabric models without there being an obvious difference between them. The use of physical mirrors and the mirror facility within Final Cut allowed me to explore ‘fictional’ folds that could never exist in reality. By layering images I was able to graphically illustrate the potential of combined hard and soft folding although such pieces had yet to be physically completed.

This imaginative exploration was carried further through drawing. In order to realise my original intention of an architectural-scale projection I re-shot and re-edited the film (★ film 7), taking it into the drawing studio to serve as a catalyst for a series of large-scale drawings of fictional, hybrid folds (fig 31). This process was an active meditation on future possibilities, examining existing artefacts through the filter of multiple media; a creative chain of ‘Chinese Whispers’. Drawing provided a way of ‘thinking in action’, an embodied exploration of concept. Drawing generates physical interaction between the drawer and the drawn. The embodied movement at the heart of this interface embedding one within the activity, negating the mind/ body dichotomy that can be present in verbal conceptualisation. Drawing is performative thinking, an attempt to capture the abstract. Through the action of rubbing out, over drawing and altering one is able to activate and reconstruct memory to produce new ideas (Oldridge 2008).

Drawing at an enlarged scale enabled me to clarify how upsizing the physical samples might work. It assisted me gauge the necessary module size for each origami unit experientially rather than mathematically as well as visualise how the transition from hard to soft fold might work. The folds depicted are not physically possible on a single planar surface. However, through drawing one is able to contemplate how these folds could be made in reality e.g. through layering or creating apertures that allow one structure to emerge through another. These visualisations provide inspiration for the evolution of future forms.

Although prosaic descriptive writing was appropriate for documentation of pragmatic process it was not flexible enough to encapsulate the burgeoning poetic aspects of the project. A wider range of writing styles needed to be incorporated to better reflect the entirety of the work. Initially, adopting more imaginative writing styles was difficult for me. I was comfortable only when writing commentaries or descriptive pieces and found I was very stilted when attempting to convey my feelings about the project. To address this deficiency I embarked on a creative writing course. This equipped me with a range of stylistic tools, facilitating a more artistic approach to my academic writing and enabling me to explore alternative conceptions of the project. Methods such as clustering, generative and free-writing helped me to capture aspects of the project using a more personal voice, important as I am embedded and entwined in my research not a detached and passive observer. Later written work reflected the gradual repositioning of my practice to encompass both technical and artistic approaches as I began to articulate poetic responses to the processes of the research.

Writing to find form, writing to find calm

My core crawls uneasy.
My writing, my research should be a taut smooth line.
Direct, straight
Pared down, pure concept.
A piano string sounding a well-tuned note,
Cradling clarity in its tension.

But as I write, descending deeper to the crux
                        My thesis kinks.
The taut thread slackens,
            Tangles,   snarls.
Attempts to untwist this knot exacerbate it,
Entangle me in its web.

Smooth string becomes frayed, barbed yarn:
      Woollen, woolly,
            Felting tighter with every move.

Locking.

A random, confused, confusing hairball.
Wisps spring this way and that,
Unruly and un-ruled.

How can I reassert control?

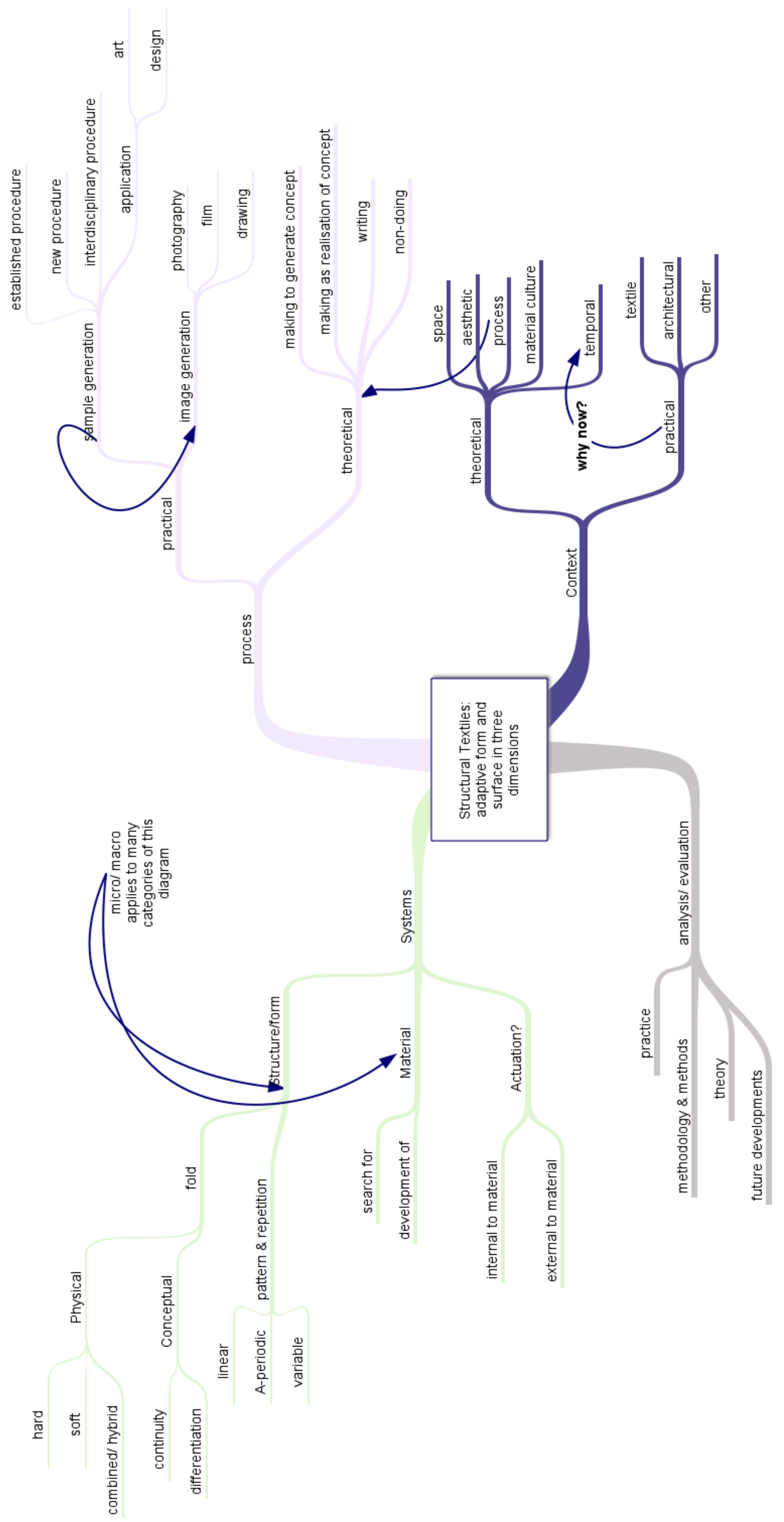


Fig 32. Mind map giving an overview of key aspects of the research project, 2009.

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Comb out this mess?

Only patience will save me,
And cast-iron nerves.
I have to trust
                  That this is possible.
Move calmly, deliberately.

Flailing to find form will only felt more firmly.
I must slowly unpick each strand,
Follow it back to its source.
```

As writing moves into the literary realm the visual is conjured by the verbal, metaphor and simile sketching with words. In a literal amalgamation of verbal and visual methods of conceptualisation I have found it useful to diagram concept and structure using mind maps that combine image and text in a graphic layout. I have used this method to plan and evaluate material as well as to clarify concept throughout the project, finding it helpful for shaping disjointed thought into coherent structure that can focus and inform the research (fig 32). Mind maps superimpose a visual organisational structure on verbal content, holistically engaging the brain in critical analysis of the problem.

> "A mind map draws on all your mental skills: the associative and imaginative skills from your memory; the words, numbers, lists, sequences, logic and analysis from your left cortex; the colour, imagery, dimension, rhythm, daydreaming, Gestalt (whole picture) and spatial awareness abilities of the right side of your cortex" (Buzan 2003, p.147)

This combination of diverse processes of conceptualisation has aided my process of categorisation, assisting the comparison and analysis of relationships between elements by enabling visualisation of the whole topic in one go. Taxonomical diagrams have enabled me to identify and reposition or eliminate "matter out of place…which must not be included if a pattern is to be maintained." (Douglas 2002) They can link theory and practice, the poetic and the technical, the ephemeral and the concrete and are repositories of knowledge and narrative as well as of artefacts.

The organisational structures of my research, for example the diagrams or databases are ambiguous. Existing to control and order information and its dissemination they create diametrically opposed positions, being simultaneously personal and public. Classification of the collection is 'designed' as much as the physical outcomes of the project and therefore ultimately subjective. What gets included and how is influenced by personal aims and interests. The editing and erasure of elements is an act of creative vandalism by the organiser, a construction of fresh narratives that can clarify or obfuscate.

> "I'll show you how easy it is to cross information from one side of the street with information from the other side of the street. The junction is where I live. There are so many lines pass through me. I am a knot, a tangle, an operator. I can cross the lines any way I want to produce sparks, explosions, ricochets and fireworks. We're talking hybrids, splices, mutants, freaks." (Beard 2008, p.44)

In practice-based research the creative potency of the taxonomist is increased exponentially as the practitioner not only searches for and categorizes the stuff of the research but also originates it.

On a practical level the taxonomic process has helped me to elucidate connections between differing production techniques and to re-examine my existing categorisation of the various samples created, pattern recognition occurring as a result of this organisational process. As Professor Kirkby demonstrates, a completely random and unstructured language becomes structured and logical with a pattern that can be applied to unfamiliar objects and situations after several iterations that incorporate errors of its users (2009). This example of gradual self-organisation highlights the importance of iterative working in developing robust taxonomies and suggests that the development of a rational structure can be intuitively developed.

A significant example of this is my diagram of practice of summer 2009 (fig 33, inside back cover). I constructed this pictorial timeline interweaving practical work with contextual references to explore relationships between these elements. Their systematic classification and organisation within a graphic taxonomy diagram enabled a more coherent and cohesive view of the complete project. This reflective exercise was an attempt to unify the separate strands of the research and resulted in the realisation that the practical work actually falls into two main categories, not four as originally perceived. Samples are formed by either printing or moulding although these categories subdivide. Moulded manipulations split into stitched, tied or card moulded. Printed manipulations divide into silk-screen printed, laminated or bonded. These techniques re-converge in novel configurations in later iterations. The diagram clearly illustrates how a basic taxonomies of process and related structure can describe multiple and complex paths.

The taxonomical diagram is not only an assessment tool, used "to identify consistency across different design processes, projects and the overall body of … work." (Moussavi & Zaera Polo 2004) but also gives an operational or process paradigm with great generative potential. Referring to the diagram could be a way of overcoming habitual practice and preconception. It encourages the deconstruction of previous end products to a series of generic elements that can be traced further and further back along their lineage, thereby surfacing potentials that may have been overlooked. Recognition of homologous structures and processes across disparate outcomes enables the targeted alteration of textiles to create transferable functionality and application. New branches can be added to the diagram as required when offspring are born from new iterations.

In such a system of organisation contextualisation of objects is given by their juxtaposition against others, their meaning relational and therefore variable not fixed. In the taxonomy the object is not a singular, stand alone item but one iteration of many, part of a larger whole, an overlapping ensemble rather than disconnected singularity. Each object within a series is compared, assessed, evaluated against not only its precursors in the series but also against those objects yet to come. Also seen in relation to other objects external to the series the single object becomes heavily steeped in temporality. This notion of objects being constantly evolving iterations on a theme raises the spectre of an object that is never finished. The series stretches out, potentially infinitely.

> "So, for me, the unfinished object is not (only) to be understood as single, 'user friendly', multi-purpose' or 'open-use' objects but as an open-ended series or system. It is about what an object might become, how it might evolve, how and with what (as well as who) it might connect, interact or evolve and so on." (Julier et al. 2009)

Taxonomy becomes a tool for the manipulation of these serial relationships to achieve specific properties. The scaffold of the taxonomy is essential in order to allow multiple components to be recombined and re-ordered at will to create predictable but novel outcomes for specific circumstances.

This chapter has compared the differing opportunities and drawbacks presented by playful approaches contrasted with more constrained methods and has shown the necessity to achieve balance between free playful exploration and containing boundaries in order for creative practice to flourish and advance beyond established methods. It has then described my use of multiple methods, discussing how I organised these outputs into a taxonomic tool that provided a structuring principle for the generation of new work.

CHAPTER 04

Chapter 4: Folding towards 3-D form

This chapter describes my survey of current production methods and application of folded textiles, probing for developmental opportunities. It then outlines my practical exploration of stitched, tied and moulded textile manipulation techniques, explaining how unforeseen outcomes of these experiments modified the focus of the project: a focus further refined by a review of practice from other disciplines using origami-type folding.

Stitched and tied manipulations

The transformative, conformable behaviour of folded textiles, capable of both stiffness and flexibility make them an ideal material for the creation of self-supporting folded form. However, an apparent simplicity of process belies the complexity and infinite potential of the outcomes. In folding a 'finite number of components yields a practically unlimited diversity of combinations' (Deleuze 2006, p.109). In order to be truly useful it is necessary to contain randomly ductile behaviour within proscribed limitations. My practice has investigated the potential for traditional, globally practiced textile manipulation techniques to be combined with other processes to create folded forms for application in diverse disciplines.

People have been folding and pleating textiles for millennia. Examples of pleated Egyptian clothing found in tombs and depicted in statuary date as far back as 2000 BC (Richards 2000) (fig 34). Pleating

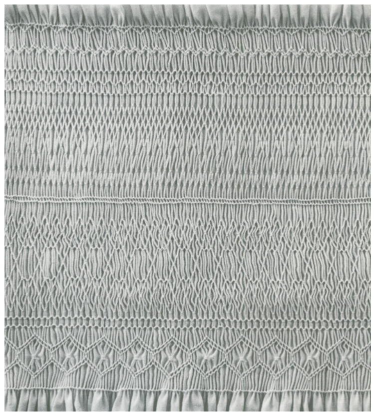


Fig 34. Torso of Nefertiti, red quartzite, approx. 1350BC. Musée de Louvre, Paris.
Fig 35. Traditional Norwegian skirts.
Fig 36. English smocking.

is prevalent in the folk costumes of numerous cultures and times and there are many similarities in the processes used for their creation (figs 35-37). The stitch techniques used for pleating skirts in Norway (Noss 2009) are reminiscent of traditional English smocking processes and are similar in appearance to pleated skirts in Thai tribal communities, although there pleats are hand crimped not stitched (P. Lewis & E. Lewis 1998). Historically created using laborious hand manipulation techniques on natural fabrics, such textiles would either have to have their folds set by stitching or they would have to be stored very carefully. Intricately pleated textiles were difficult to clean and needed reshaping on a regular basis. Even as late as the early 20th century, Fortuny gowns of micro pleated silk had to be sent back to the couture house on an annual basis in order to be re-pleated (fig 38).

Contemporary pleating and shibori practices have been transformed by the advent in the mid 20th century of thermoplastic materials like polyester, that have shape memory capabilities allowing permanent, washable folds to be created. In the 1980's and 90's fashion designers such as Issey Miyake and Junya Watanabe notably took advantage of advances in synthetic textile manufacture to create apparently randomly creased and crumpled garments that confronted and confounded social norms (fig 39). Intentional folds took on the appearance of the unintentional, as the traditionally 'low status' crumpled appearance that had previously indicated a lack of care, a lack of discipline and even poverty became 'high status'. It could be argued that in doing so these designers created the category of the 'semi-controlled' fold. A fold partially dictated by the maker that allows the unpredictable process to dictate the precise details of the outcome.

Founder of fashion label Ghost, Tanya Sarne brought crinkled textiles to mass markets through high street stores such as M&S in the late 80's, creating easy-care fabrics that eased movement and enhanced fit. Such fabrics were further popularised in the early 1990's by Yoshiko Iwamoto Wada

Fig 37. Thai tribal textiles: Hmong skirt.
Fig 38. Detail of a Fortuny 'Delphos' gown.
Fig 39. Partially crushed and tied polyester dress, Issey Miyake, A/W 1993/94.

(2002, p.149), who was instrumental in developing the pocketTee (fig 40) using miura shibori techniques that mould the cloth into a series of small hillocks, creating an extraordinarily elastic surface that can expand or contract to a factor of three whilst still maintaining its shape.

Textile designers such as Michelle Roberts (fig 41) and Yuh Okanao (McCarty & McQuaid 2000, pp.72-73) (fig 42) have also exploited the shape memory properties of polyester, using kumo and marble shibori techniques to create strikingly sculpted 3D textile forms (Yoshiko Iwamoto Wada 2002, p.165 & 186). Employing a different approach Sharon Baurley (1997) developed compression moulding techniques on polyester that create decorative 3-D effects. In 'Fossil Interspersed with Pleating' (fig 43), Baurley combines two different moulding techniques to create diverse folding types. This gives the fabric an intriguing differentiated textural surface and provides potential for multiple behaviours that inspire further investigation.

Building on work undertaken prior to my PhD research (see Appendix 1), I made a number of samples using a range of the stitched and tied manipulations outlined in Wolff (1996) and in Wada et al (1999) (❖ samples 1-3/9a/16: figs 44-46). My primary purpose was to familiarise myself with a variety of traditional textile manipulation and shibori techniques and to investigate if any aspect of the process might be transferable to other materials or applications. I manipulated the fabric into its desired shape before steaming it at 100°centigrade at atmospheric pressure or baking it at a temperature of between 200° and 220°centigrade for 15 to 30 minutes. The selection of temperatures and timings are dependent on the type of fabric used. For example, mixed fibre blends, fabric weight and structural differences such as woven or knitted construction all affect outcomes and successful results can be attained with lower temperatures and shorter durations.

Fig 40. PocketTee – Yoshiko Iwamoto Wada.
Fig 41. 'Cross-pollination', Michelle Roberts.
Fig 42. 'Pearl Bubbles', Yuh Okanao.

Fig 43. 'Fossil Interspersed with Pleating', 1993, Sharon Baurley. (top left)
Fig 44. Stitched regular diamond, sample 1. (bottom left)
Fig 45. Stitched irregular wave, sample 3. (top right)
Fig 46. Muiri Shibori, sample 13. (bottom right)

Stitched and tied shibori techniques carried out on non-elastic fabrics generally create soft, organic folds making a very elastic, pliable material that can easily be moulded or curved around 3-D forms. The amount of and direction of this elasticity can be controlled by the stitching or tying pattern. A variety of effects can be formed on one length of cloth by altering stitch type, length and pattern, giving differing depths of ruching. Thus shibori can be used to create complex shaping without seaming, giving versatility across many applications, and comfort and freedom of movement when used for apparel. However, the techniques applied in the early stages gave only low relief textures rather than more marked structural, three-dimensional effects. Additionally, the 3-D forms created by the shibori techniques were organic, imprecise and not entirely predictable. As a result of this, stitching and tying were set aside in favour of other processes for a long period but were rediscovered later in the project.

Selection of Materials

In the early stages of my research I used polyester and mixed composition dressmaking fabrics predominantly as I learned new techniques, due to their accessibility, to my familiarity with their behaviour and to their thermoplastic properties (described above). These shape memory capabilities have proved to be particularly useful for the creation of transformable 3-D form throughout this project although I have also experimented with natural and semi-synthetic materials.

Throughout my research I have selected materials for both functionality and aesthetic, aiming to achieve an acceptable balance between the two by selectively exploiting advantageous material characteristics and minimising or adjusting less attractive properties. Materials influence object identity by engaging our senses to arouse memory and emotion, affecting the user at conscious, sub-conscious and unconscious levels. Using the same design and production technique but varying the weight, structure and composition of the substrate can transform the outcome, altering not only the form and properties of the material but also its aesthetic and its effect on the user. Emotional value judgements are made about products separate to their functionality. For example a willow laundry basket may be seen to have inherent value, longevity and authenticity whereas its plastic counterpart is perceived to be throwaway and of low value. In cases when a material possessed interesting behavioural properties but was otherwise unattractive I explored ways in which the aesthetic, sensual and emotional impacts of the outcome could be improved.

As the research progressed I visited trade fairs, shops, materials libraries and consulted specialists at organisations such as the Institute of Materials to increase the range of substrates available to me. Still predominantly composed of polyester but designed for diverse application in areas such as filtration,

Fig 47. Close up sample shot w red chalk.

footwear and sailing, these substrates had wide ranging aesthetics, structures and behaviours. As my repertoire of processes expanded a selection of these were incorporated into my project.

I purposely restricted the colour palette of my materials, the majority of my practice retaining the whiteness of the un-dyed substrates used. This removal of extraneous distraction focused attention on the forms arising from folding. Using white controls and limits difference, reducing the form to clean geometries unbroken by colour changes.

> "White can be seen as a basic form of life or information that emerges from the chaos." (Hara 2009, p.10)

It is a method of simplification, a paring down to highlight essential elements. The lack of colour not only emphasizes form and surface pattern given by subtle variations of light and shade across the undulating textiles but also draws attention to fine gradation of whiteness in different materials, highlighting their distinctive characteristics and textures.

Our visual experience of colour is bound up with our sensory, bodily contact with objects of that colour, their tastes, textures and smells.

> "In this regard, color is not understood through our visual sense alone, but through all our senses." (Ibid, p3)

Part of our experience of white, an empty plate waiting to be filled, a blank page waiting to be marked, places expectancy of things to come at the heart of our response to it. To my mind limiting the palette to white retains an element of the tabula rasa present at the beginning of the design process, designing in possibility and the potential for change.

Whiteness is a transitional state. It is uncompromising. Marks and blemishes appear on the surface that bear witness to my struggle to generate form. Error shines out from its spare ground, unmitigated by the camouflage of colour. However, these errors drive me to repeat and revise, to strive for an unobtainable perfection. The purity of white can be a point of meditation, a calm ground from which clarity and detail can emerge. Framed by white these details in turn become a focus for meditation (fig 47).

Paper pleats and textile origami tessellations

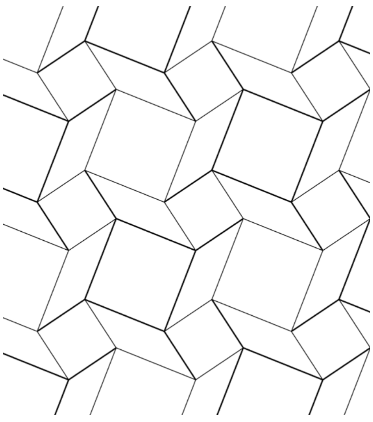
My physical exploration progressed from soft, semi-controlled folding created by stitching and tying to more precisely controllable origami, in which a diverse range of aesthetically pleasing, complex forms can be created from geometrically simple arrangements of folds.

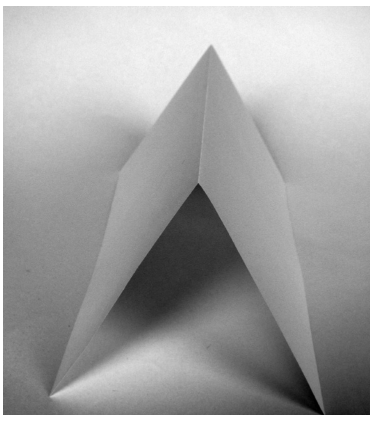
To improve my practical skills I started making paper models, folding some of Alex Bateman's tessellated geometric designs[1] (Bateman n.d.) (fig 48). Origami tessellations are created by folding a repeating series of pleats and twists across a single, uncut sheet of paper and can make extremely complex, decorative patterns. This pattern has the potential to delineate structure and form. Using origami techniques to mould fabrics creates sharp creases that can impart a semi-rigid structure to otherwise supple substrates due to their geometric arrangement. Form arises from the frequent and repeated placement of this extremely fine, folded structure.

I found the rhythmic abstraction of the tessellations very appealing, offering great imaginative scope for the creation of customisable form. Although such designs appear at first glance to be essentially 2-D and therefore not obviously relevant to my intentions particularly when compared to other very 3-D origami forms based on flora and fauna, existing 3-D models seemed much more restrictive; their forms set, often immovable and not obviously applicable in different situations.

When folding origami tessellations in paper the pre-creasing of folds is essential both to set a framework for the design and to facilitate the complex, multidirectional folding. I move diagonally across the sheet;

1 Shuzo Fujimoto is regarded as the primary originator of tessellating origami patterns, developing the pivotal 'twist' fold in the late 60's or early70's (Gjerde 2009)





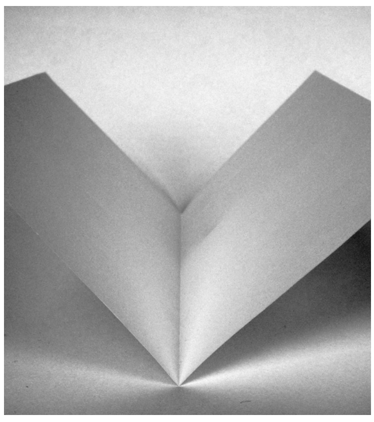


Fig 48. Square dance origami net, Alex Bateman, 1997.
Fig 49. Mountain fold.
Fig 50. Valley fold.

fold, unfold, fold, unfold, a rhythmic process repeated numerous times. Folding is an embodied and dynamic improvisational method, a diagrammatic technique giving understanding through positive action (Vyzoviti 2006). The reverse practice of unfolding can be equally informative, encouraging inductive reasoning through backward working. As I progress mountain folds (fig 49) turn back on themselves, becoming valley folds (fig 50) but I encounter problems translating 2-D instructions into 3-D actions. Misunderstanding is rife, hindered by my lack of origami expertise. During abortive attempts at folding my frustration becomes physically manifest in the frayed, tired models that crease in the wrong places as well as the right. Both intentional and unintentional folds become a traceable history of the material's interaction with external forces.

Repetition slowly leads to an improvement of my skills and knowledge, enabling the folding of progressively more complex tessellating patterns. Active exploration through physical folding and unfolding develops my understanding, eventually enabling reasonably accurate prediction of the behaviour of any given fold. The successful completion of a model gives a glowing sense of achievement alongside profound feelings of relief. I appreciate the imperfect outcomes of my activity as traces of lessons learned, the paper bearing the scars of my multiple attempts to get it right. However paper has many limitations as a modelling material. It is not suited to creating soft draping folds, is liable to tear and disintegrates when wet. Additionally it ceases to support its own weight in structures above a certain scale.

Building on my own previous experience and commercial techniques for permanently pleating and folding fabrics I began experimentation with transferring origami designs on to cloth.

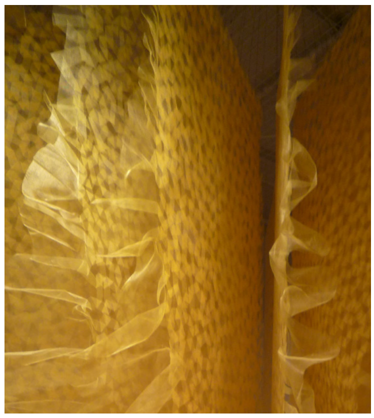


Fig 51. Dancers from the Frankfurt Ballet in 'Pleats', pleated polyester, Issey Miyake, 1991.
Fig 52. Fish dress, heat transfer and pleating on polyester, Yoshiki Hishinuma, 1997.
Fig 53. Installation by Kazuyo Onoyama. Gallery Gallery, Kyoto, Japan, 2008.

Fig 54. 'Princess' pleating machines Inoue Pleats Co., Ltd. Fukui, Japan, 2008. (left)
Fig 55. Ciment Pleaters' cardboard moulds. (top right)
Fig 56. Worker making 'sunray' pleats at Ciment Pleaters, Potters Bar, UK, 2005. (bottom right)

Commercial pleating practices

Issey Miyake (fig 51) and Yoshiki Hishinuma (fig 52) have made extensive use of controlled moulding techniques in tandem with heat setting for the formation of their three-dimensional and textural fabrics (Yoshiko Iwamoto Wada 2002). Kazuyo Onoyama, a textile artist from Osaka folds fine, non-elastic substrates freehand using a small iron to create her installation pieces (fig 53). However, a more common technique for transposing designs onto cloth is by clamping the textile substrate between two identically folded moulds of paper, card or foam before steaming.

My visits to F. Ciment (Pleating) Ltd, Potters Bar, UK and Inoue Pleats Co. Ltd, Tokyo, Japan in 2005 and 2008 respectively have provided an invaluable insight into the industrial production of such fabrics. For many years both companies have pleated textiles by machine and hand, predominantly for apparel but also for interior design applications. Although simple folds such as accordion, box and crinkle pleats are machine made (fig 54) many of the more complex designs necessitate the hand folding of card moulds (fig 55 & 56) and are therefore extremely labour intensive. The logistics of such complex hand folding restricts piece sizes of these fabrics to a width of not more than 2.5m and a length of 3m. However, each mould can make over 100 fabrics before failing.

The significantly larger scale of production at Inoue Pleats Co. Ltd, has led to differences in the manufacturing process. At F. Ciment (Pleating) Ltd complex pleat moulds are hand-made using 400-450gsm card, or 300gsm card for finer pleating, taking up to 6 weeks to complete. Two layers of card are laid out together and pin marked to register them correctly. Both the top and bottom moulds are exactly the same size. The design is then scored with a tool resembling a bent braddle that bruises the card. To insert fabric into the mould the lower card is stretched out flat and weighted, the textile being laid on top before the weighted top mould is placed in alignment with the bottom card. These three layers are folded as one, rolled and steamed at atmospheric pressure for approximately 20 minutes.

At Inoue Pleats Co. Ltd, card moulds are computer designed and laser scored, speeding up the process considerably, although complex designs can still take up to three days to fold. The resultant package is kept flat when placed in an autoclave for heat setting. Foam inserts level the height of the textile and card layers which are clamped between foam lined wooden boards. A vacuum is used to expel the air prior to steaming to ensure an even temperature setting across all areas of the fabric surface.

The vacuum is also used to cool the package after steaming. Garments are often made up (without fastenings) before pleating with many mass-produced pleated clothes still made entirely or partially by hand.

In addition to standard moulded folding techniques Inoue Pleats Co. Ltd, has developed a technique that enables the creation of lasting pleats on silk and wool using a chemical process similar to that of hair 'perming'. They also employ a specific technique for soft pleating using shaped foam moulds instead of heavy card.

Personal development of textile pleating process

In initial experiments to transfer origami structures onto cloth I experimented to find the ideal weight of paper for the moulds. The card I had used prior to this project to mould simple folded structures was too thick for the densely folded tessellated designs, making it difficult to get sharp, precise creases. Using 80gsm paper I folded two identical copies of a Bateman origami design, unfolding them in order to insert the fabric before refolding. Clipping in strategic places as the folding progressed controlled the natural exuberance of the fabric and the paper retained some memory of its folded form, facilitating the process. Once completely folded clips were no longer needed as the form held in place under its own tension. The folded layers were placed between two Teflon sheets and pressed at 200° centigrade for 30 seconds (❖ sample 14: fig 57). I used the heat press to set the fabric as it was quicker than steaming and the combination of pressure and heat gave crisp edges to the folds without the need for clamping between boards, although it also flattened the resulting fabrics.

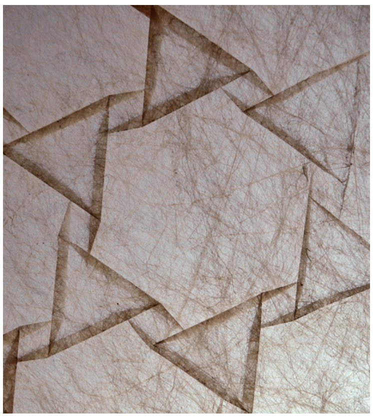
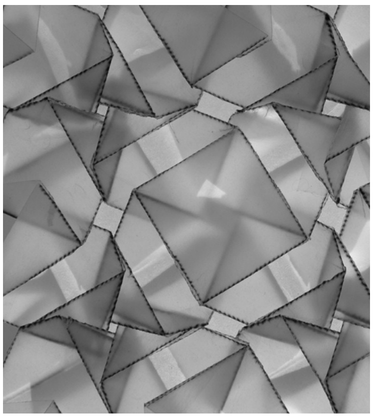
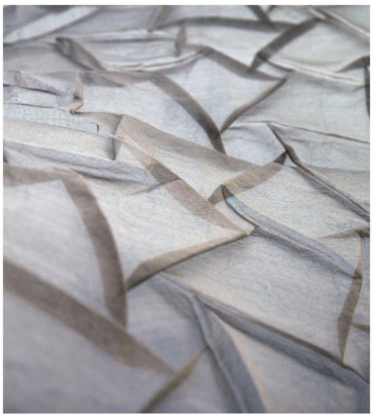




Fig 57. Moulded polyester, using Alex Bateman's pattern '3.6.3.6 tesselation 22.5 degrees 3 scaling', sample 14.
Fig 58. Origami folded tracing paper.
Fig 59. Moulded silk organza, using Alex Bateman's pattern '4.3.4.6 tesselation 30 degrees 0.5 scaling', sample 15.

First attempts at transferring the folded paper designs onto fabric were problematical. Unfortunately the 80gsm paper moulds were not sufficiently robust, having a tendency to buckle and distort, necessitating the testing of heavier weights of paper for future experiments. More difficult to solve was the realisation that the fold has contradictory mathematical and material existences. The perfect geometry of the origami net is an immaterial entity applied in a material world. Geometry disposes you to think in absolute forms when in reality physical planar surfaces have measurable thickness; the fold itself has a dimensionality that impacts on the viability of the design. Small deviations from the “perfect” fold add up to large deviations when multiplied across a surface or structure. When folding three layers together the additional thickness introduces an element of ‘creep’ that compromises the accuracy of the folded pattern after a certain distance. This factor accounts in part for the limitation to piece size in commercial production of complexly folded fabric. Due to their inherent materiality these models refused to fold precisely, being only approximations of the perfect fold.

I briefly considered making one mould slightly larger than the other in order to improve the fit, however as each card enfolds the other the mould would need to be simultaneously larger and smaller, a physical and mathematical impossibility on a single plane. I then tested the suitability of heat fix paper as a mould, thinking that a reduction in the number and thickness of layers might improve the accuracy of the pattern. However, even when using very light fabric the heat fix paper peeled away from the fabric at the folding stage, rendering it useless.

Further experimentation revealed that paper moulds comprising of one sheet of 150gsm cartridge and one sheet of 200gsm cartridge gave a good combination of stiffness and flexibility and worked well with a variety of substrates including lightweight polyester, silk organza and cotton lawn. To minimise pre-creasing I photocopied the origami nets onto the moulding paper but discovered that the black lines of the photocopy transfer to the cloth during the heat setting process. After this point I was careful to ensure that these black lines always fell on the outside of the mould, not in direct contact with the fabric. As I was using paper rather than more robust card the moulds become brittle after a few uses due to the dry heat of the press. However later in my research I discovered that elephant hide, a parchment type paper available in medium weight 110gsm paper or heavier 190gsm card, had greater durability for moulds intended for repeated used.

Inspired by Eric Gjerde’s (2010) use of translucent paper to highlight the decorative elements of tessellated origami designs I used tracing paper to test some origami designs (fig 58). Although it made very decorative models where light patterns created by the layering of folded areas were clearly visible, tracing paper was not a practical medium for folding as it was too brittle and kept splitting during the process. Building on this idea I chose a lightweight, translucent 100% silk organza (❖ sample 15: fig 59) for my second origami experiment. However the combination of an open folding pattern with this insubstantial material although decorative, was too flimsy to hold its shape well. ❖ Sample 14, which used paper-like 100% polyester was more successful due to its stiffer handle. Additionally problematical in these initial experiments were the undercuts of the Bateman origami nets. Although proportionally good on paper, they were too shallow once translated into cloth.

It was necessary to develop original folding patterns in order to give a greater control of the pleat angles as well as a greater autonomy over the aesthetic and potential function of the design. Initially I evolved designs through computer modelling. 'Tess 1.2', a tessellation-generating programme developed by Alex Bateman specifically for the purpose of generating origami nets facilitated my design process, allowing the effect of folding to be seen in advance. I designed a series of folding nets using this software to adapt and amend generic folding patterns, controlling basic pattern structure and enlarging undercuts (fig 60). Although Bateman stated a pleat angle of no more than 30° was necessary in order to create foldable patterns I found through practical experimentation that origami nets where the angle was 40° were still foldable in paper whilst at the same time creating a fold of much better definition on textile substrate.

I employed this CAD design software to develop tessellated origami structures on natural fibre substrates in a collaborative project with students from weave, accessories, menswear and womenswear for sportswear manufacturer Umbro, focusing on bodily applications for the textiles created (figs 61 & 62). As a group we concentrated on the development of multipurpose garments using pleats instead of seaming. For the intended luxury market natural fibres are arguably more appealing, having a more pleasant handle and appearance than the 100% polyester samples.

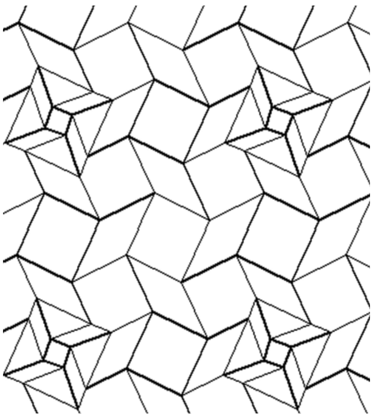


Fig 60. Origami net designed using 'Tess' software.
Fig 61. Moulded hexagonal fold coated silk- organza, sample 17.
Fig 62. Moulded square fold coated cotton lawn, sample 20.

In an attempt to improve the permanency of the heat set folds on a variety of natural substrates I coated cottons and silks with a liquid polyester solution “Miracle Liquid”, manufactured by Omega Dyes to enable transfer printing with disperse dyes on non-polyester substrates. The affect of the coating on the handle of the fabric depended on its composition. On the cotton lawn the change was barely perceptible but on the silk organza it had a noticeable stiffening effect that contributed to the strong holding of the heat set form, a positive attribute in this context. The outcomes of these experiments were a series of visually arresting, intricately folded fabrics that changed dramatically when stretched (❖ samples 16,17,19 & 20: ★ film 4). Manipulations carried out on sheer polyester-coated silk organza gave an attractive, complex geometric pattern that held its form well and was particularly prominent when backlit. However these intricate folds did not withstand washing in water well, despite their polyester coating. I had also added colour to some samples by transfer printing with disperse dyes but these proved to be unstable, changing hue over a number of months.

While the use of CAD software allowed the relatively easy generation of folding patterns, when using my computer-generated nets I didn’t fully comprehend the connection between the flat diagram and the resultant form. My inability to predict the effect of my manipulations at the CAD stage limited my control of the 3-D outcomes. Joseph Lim notes,

> “When the representational means becomes the media in which the design process operates, then the construction/ material system is constrained by the representational means” (Lim 2009, p.9)

Although I was able to adjust origami designs quickly using ‘Tess 1.2’ I had no underpinning theoretical understanding of the process. Usually I construct physical models intuitively, employing my

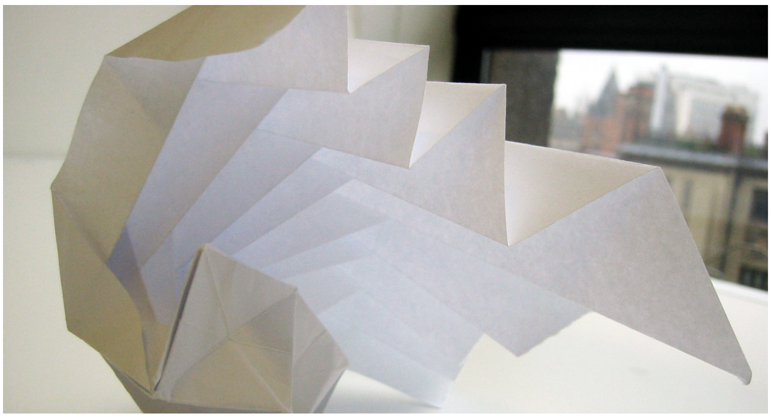


Fig 63. Chris Palmer flower tower.
Fig 64. Paper origami model free folded (not from printed nets).

understanding of the relationship between materials, process and form to create complex geometries without fully understanding the abstract mathematical principles that govern them (discussed further in chapter 5). Using CAD to create designs allowed no opportunity for such embodied understanding, leaving me unable to predict how adjustments would affect the outcome (discussed further in chapter 6). I found that without this understanding I was unable to adapt the CAD designs in any systematic way. I felt that the tessellated origami patterns showed potential for further development into more structural three-dimensional shapes, such as the flower tower created by Chris Palmer (fig 63) that I was unable to realise within the constraining parameters of the 'Tess 1.2' software.

I began working through my ideas directly on paper, thereby incorporating 3-D structure into the design process from the outset (fig 64). Yet while folding with no pre-designed net was initially liberating, being more in tune with my natural way of working, my lack of knowledge of traditional origami techniques severely constrained my output. Working through a comprehensive series of exercises outlined in Lang (2003) I expanded my vocabulary of folding, learning how to customise and adjust classic bases to create novel designs. I was concerned that this very time consuming endeavour might prove to be a blind alley but ultimately it dramatically changed my working methods for practical research. Although for an extended period I had been extremely resistant to the idea of following well-tried instructions for the folding of various 3-D forms e.g. flora and fauna, I came to realise a great number of transferable skills could be acquired in this way.

The Belligerent Fold

An exercise in frustration: attempting to understand the fold.
Commencing with an illustrated text,
            an exegesis on the minutiae of practical folding.
At first impenetrable but then a flash, a moment of clarity.
      No, I get it, I do.
I understand the theory.

But now the actuality.

The diagrammatic schema is laid out before me… an optimistically unmarked sheet awaits manipulation.

I start
Physically, physicality, tactility, motion
The rhythm of a well-trodden path

A bird for a base
A bird for a base
A bird base

I've been here before

Countless times

I am at home…
for now
for a minute
But then…
What is this?

OK, I see
Fold like this, crease here
A mountain, a valley
Just as it says
The creases are just as it says
WHY WON'T IT FOLD?!

The fold is belligerent
It wilfully refuses to comply

From flat map
jumping to 2-D image of 3-D thing
Incomprehensible
The layers, the passing time
Both absent.
Precision is absent
Detail is absent
So, into this lack, this void, I jump
Twisting the paper this way and that
Questing
Hours pass

So quickly

Holes are worn through the conflating intersections

        But still No solution
                  No progression
                  No understanding

Holes are worn through my composure
The paper is frayed
I am frayed
The thread securing my patience

                                    snaps

That’s it
I’m through

I break

And what comes of this?

A mutilated songbird with a clubfoot.
            Incomplete
                  Not because I can’t, I choose not to.
I have learned what I need from this model.

The well-rounded chest
The angle of the legs, just so
                  was not my aim

I have learned about grafting
            Borders and strips
I have gained new eyes
            Dissecting patterns
                  into

                                          Single motifs

Reassembling

In

Uncharted

Configurations

It was a good exercise.

On developing a greater understanding of traditional origami bases as well as the relationship between crease pattern and folded form I could experiment more intuitively with structure and pattern. R.J. Lang avers,

> "By cutting and assembling pieces of existing bases into new bases, you can break out of the rigid hierarchy of the traditional bases and realize entirely new custom bases" (Lang 2003, p.157)

Being able to employ a variety of folding techniques and to identify the potential behaviours of such folds fostered a more fluid way of working in which structures could evolve iteratively. Origami nets were now documented from the models rather than dictating outcomes.

Reflections on early practical explorations

I employed similar processes to commercial pleating companies to make my initial origami folded fabrics but through these experiments identified potential areas of development. Commercial textile pleating companies use paper and textile substrates in a very limited weight range and design sizes

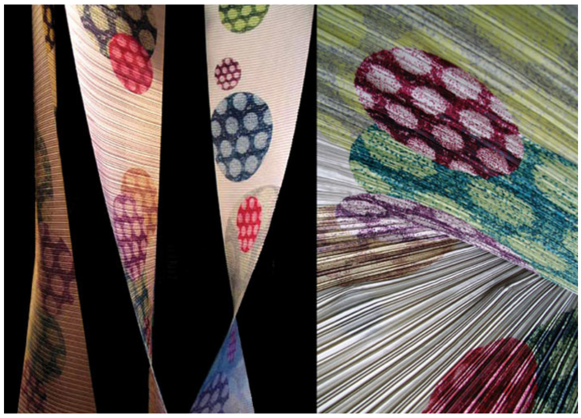


Fig 65. Blizzard, pleated polyester, Inoue Pleats Co., Ltd. 1996.
Fig 66. Y-Walls? Textile screening.

used are almost exclusively restricted to small-scale, modular repetition (fig 65), possibly due to the limitations of the card moulding process. However, relying solely on the fold to impart enough stiffness to render light textile substrates such as these self-supporting limits both the scale of the structure and of the individual folded units within it. This leaves scope for the development of techniques suitable for the industrial production of larger piece sizes and scales and also for experimentation with non-textile substrates.

Commercially produced folded fabrics have been predominantly created for decorative effect, although some industrial non-wovens, rubbers and plastics are pleated for use as insulators in automotive and bus batteries or for use as sound insulation. For example, functioning as flexible screen or wallpaper substitute ‘Y-walls?’ enables interior space to be re-shaped, making it easy to section off areas as necessary to customise the built environment (Baid 2006) (fig 66). These conformable, pleated textiles have magnetized anchor points that attach to the existing structure of the building, providing the core form, while the set folds contribute to the ability of the form to bend and twist without sagging. Although they are easy to install, transport and store, ‘Y-walls?’ offer little to no thermal or acoustic insulation properties. Printed surface pattern enhances the decorative effect but is totally independent from the structure. This tendency for folded textiles emanating from the discipline of textiles to emphasize aesthetic over function leaves scope for the investigation of alternative folding patterns, motifs and materials to create performance-enhancing form or multi-purpose functionality.

Knowledge of material behaviour and 3-D formation techniques acquired through practical work altered the focus of my project. The original aim of this research was to create 3-D form on textile substrates but the fabrics produced displayed an unforeseen potential for transformative behaviour. Adjustment of boundary tension of these samples results in significant structural changes with consequent changes

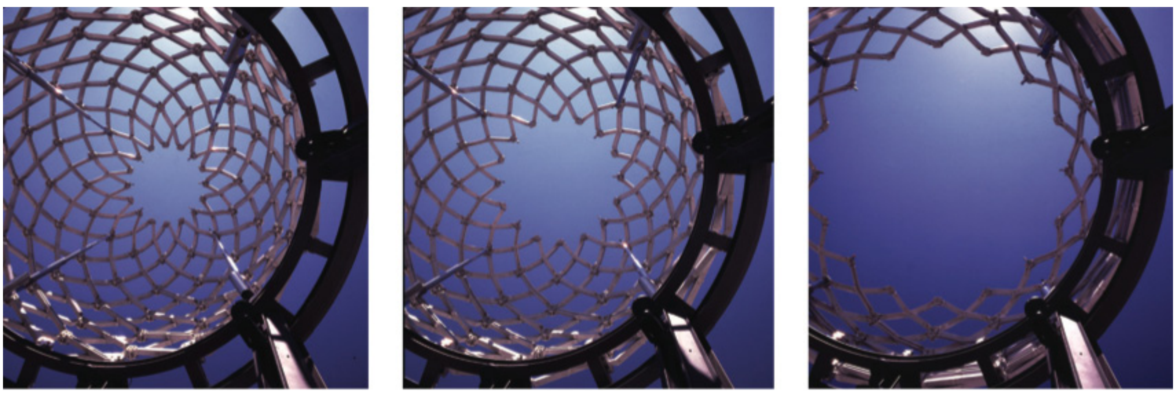


Fig 67. Iris dome, 2000’s World Fair, Hanover, Germany Chuck Hoberman 2000.

in physical properties, e.g. light transmission and thermal insulation. The origami folded samples although less malleable than those moulded by shibori type folds, imparted more structural integrity to the substrate and had the advantage of controlled packing and deployment. Benefits of deployable structures include ease of construction, transportation and storage but also the potential for adaptation and customisability leading to multi-functionality.

Application of commercial textile pleaters' product is predominantly limited to fashion textiles or domestic interiors, very occasionally branching out into product design and fine art in collaboration with select artists and designers. Yet my contextual survey revealed potential for development of such textiles in a plethora of alternative applications in diverse disciplines. Numerous designers in other fields are exploiting the fold as an agent of transformation and subversion merging strategy and property to disrupt, differentiate and articulate continuous material surface.

Sculptor and engineer, Chuck Hoberman (2010) exemplifies the potential for transformable form to be transferable to multiple purposes and scales. He designs articulated structures that function as toys, furniture or retractable roofs, dependent on scale and folding pattern (fig 67). The regular geometry of these forms facilitates the calculation of loads and stresses acting on the structure, making their behavior predictable. However, direct object scaling, without making adjustments, can create unexpected material or structural behaviours. Although the general design concept remains the same, as the scale of the design changes so must details of the structure as well as the materials used for construction. As overall mass increases there is a disproportionate increase in the loads and stresses on the supporting framework, necessitating adjustment to their proportion and density. Haldane speaking of scaling in nature states,

> "For every type of animal there is a most convenient size, and a large change in size inevitably carries with it a change in form." (Haldane 1926, p.1)

Accordingly the 'Hoberman Sphere', a toy ball expanding from 24cm to 76cm in diameter, is a lightweight hinged, plastic skeleton whilst Hoberman's stadium roofs are substantial two-part 'mesh and membrane' configurations that suspend durable fabric coverings from robust hinged metal frames.

The range of potential application of these transformable structures can be further enhanced by the use of emerging 'smart' or 'performance' materials. The exacting demands of transportation and the harsh operating environment in space have necessitated the development of exceptionally adaptable, lightweight, packable objects that have very high stability and rigidity once deployed. A rigidizable isogrid boom created by NASA and ILC Dover also uses a two-part 'mesh and membrane' structure. A mesh skeleton in a triangular grid structure reminiscent of origami folding patterns provides structural support for the attached carbon filament covering, a textile tough enough to withstand this extreme environment (fig 68). The shape memory epoxy mesh automatically deploys when it achieves a certain temperature. Such tubular forms can vary in scale enormously, measuring between 0.3 centimetres and 275 metres (McQuaid 2005, p.121). Although the boom is simply folded to attain its packed size, the combination of such self-actuating materials with origami packing has potential for wide application in other disciplines.

Kuribayashi and You's origami folded tube functions as a medical stent and is used to maintain the integrity of bodily ducts such as arteries or the oesophagus (fig 69). Its isogrid structure, similar in pattern to the rigidizable boom, comprises of a cylinder of shape memory alloy with a triangular pattern of integral stiffeners on one side, creating a planar surface of variable stiffness that is self-supporting and self-actuating. It is used in micro scales with ingenious results. Collapsed down to minimal size for a less invasive insertion procedure the stent pops open in its final location on attaining body temperature, providing sufficient support to keep the channel open. Employing shape memory materials throughout the structure removes the need for manual deployment of the implant required with current 'mesh and membrane' stents. Like the boom structures, stents are commonly made as a structural mesh covered with membranous sleeve. This design advance merges mesh and membrane into one structure, making it inexpensive to make and scaleable to fit the shape of any site (Kuribayashi & You 2002).

A larger-scale example of a single-surface origami structure is Jörg Student's rigid emergency shelter (fig 70) based on the folding structure of a hornbeam leaf (fig 10), previously discussed in chapter 2. Deviating from the usual tent construction of poles supporting a textile membrane a polypropylene sheet is scored on a roll press machine before being folded into shape, the flexibility of the material allowing for unlimited deployment and retraction of the form. The erected 'Ha-Ori' shelter has a 3.8m

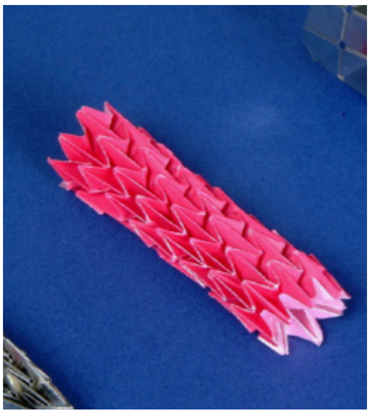


Fig 68. Deployed and packed rigidizable isogrid boom. ILC Dover and NASA.
Fig 69. Helical folding tubular stent, Kuribayashi and You.
Fig 70. 'Ha-Ori' shelter, Jörg Student, 2004.

diameter and is 2.6m high but packs easily, in minutes to a footprint of just 2.74 x 0.46m. The integration of mesh and membrane into a single structural surface streamlines the manufacture of such forms, removing the risk of multiple layers separating and improving economy, efficiency and aesthetic.

Perhaps due to industrial constraints textile pleating companies have not fully explored the potential for origami techniques to be used in much larger scales with more robust fabrics nor have they have developed substrates specifically for folded manipulation. Although Inoue Pleats Co. Ltd has experimented with resin-impregnated paper to create screens for interiors the washi paper used is a similar weight to their textile substrates, as like these textiles the paper is also moulded in card before being stiffened with resin (fig 71). These designs become uniformly stiff and immobile once the resin has cured.

Having discovered the transformable potential of my samples, full mobility of the finished form became of key importance to me. I wanted my folded substrates not only to be self-supporting, needing no frame and minimal anchoring points but also to be dynamic, morphing between predetermined packed and open states when compressed or stretched. I intuitively rejected those forms that didn't hold their own form successfully e.g. ❖ sample 37 (fig 72), as I didn't want to restrict the origami forms by setting them with resin or stitching. The opportunities for development presented by adaptable structure had captured my imagination. However, practical experimentation and contextual research has demonstrated that using light textile materials and industrial moulding techniques limited the scale of my work. In order to preserve a single-skin structure while remaining self-supporting at larger scales a different approach to materials and construction was needed.



Fig 71. Moulded resin impregnated washi paper, Inoue Pleats Co., Ltd. 2008.
Fig 72. Printed, flocked and folded polyester, sample 37, 2007.
Fig 73. 'Infold' chair, Rupert McKelvie, 2008.

I saw an opportunity to develop textile substrates with variable stiffness, on which origami folds could be produced at larger scales and without moulds. This would allow the hinges to remain flexible enough to fold whilst preventing unfolded expanses from distorting. Examples of such an approach can be seen in a number of disciplines. Rupert McKelvie's 'Infold' chair, exhibited at 100% Design in 2008, creates a variable stiffness surface by bonding plywood and formica to a rubber sheet (fig 73). The resultant planar sheet can be quickly folded, becoming reversibly packable furniture that requires no tools or adhesives for assembly. Like the origami stent, this inverts the 'mesh and membrane' structure, stiffening the planar areas, leaving the hinges soft and flexible. However, the chair's construction bonds rather than fuses two separate materials, retaining the drawbacks of 'mesh and membrane' structures, for example the risk of separation of the bonded materials.

A technique that creates amalgamated rather than bonded variable stiffness substrates has arisen from the work of Frances Geesin. Her PhD research (1995) investigated the structural manipulation of fabrics and fibres, developing the process of electroplating textile substrates to stiffen them (fig 74), fusing metal and material. This research has provided inspiration for a cross-disciplinary, collaborative project between the Royal College of Art and the University of Bath encompassing the PhD project of Tine de Ruysser. Tine's research (fig 75), completed in 2010, explores the creation of deployable structures by combining the stiffening effect of electroforming onto textiles leaving untreated textile hinges to enable origami folding. Her textiles are predominantly for jewellery and fashion applications but with potential use in a number of areas.

Tine's folded units are small scale, similar in size to those of Inoue Pleats Co., Ltd., limited by the size of the tanks that contain the electroplating solution but her structures have no shape memory property. The metal plates formed through electroplating are too heavy to be supported by their light polyester

Fig 74. Silver Rolls, heat-treated and electroplated spacer fabric, Frances Geesin, 2008.
Fig 75. Copper and polyester electroformed, origami folded textiles, Tine de Ruysser, 2009.

or cotton substrates. A few hold their three dimensional form due to the locking properties of particular folding patterns e.g. a number of tubular forms but the majority fall out flat unless stitched at the edges to constrain their form. The unstitched forms are complicated for the non-expert to refold but stitching locks the form to some extent reducing its adaptability and dynamism. Her stitched structures are only mobile when pressure is applied perpendicular to the surface and are not responsive to lateral forces. This reduction of movement might be acceptable when such structures are used for jewellery however I felt that mobility and adaptability were important criteria for my textile products. I therefore endeavoured to retain the full range of movement of my structures, relying on the shape memory capacities of the substrates combined with lightweight stiffening materials rather than permanent stitching (development of these structures discussed further in chapter 6).

If carefully designed a substrate of variable stiffness could accommodate a variety of folding types; potentially combining the benefits of the predictable behaviour of origami structures with the extreme flexibility of form given by shibori techniques or the self-folding capabilities of printed and laminated folds (these latter processes are discussed further in chapters 5 & 6).

As I developed new forms it became apparent that my textiles, as well as being autonomous physical entities, existed as models of speculative design, suggesting potential functionalities and opportunities for applications unforeseen at the start of the making process. By situating my project at the boundary between pure and applied research as well as between art and design I was not so constrained by commercial considerations and therefore had more freedom to explore the possibilities of speculative concepts and applications as well as non-commercial outcomes.

This chapter described how after surveying current production methods and application of folded textiles I recognised the potential to address limitations to module and piece size in industrial pleating techniques. It then outlined my practical explorations using stitched, tied and moulded textile manipulation techniques and explained how unforeseen outcomes of this process refined the core of the project to focus on the development of adaptable, deployable form. A review of the use of origami-type folding in other disciplines refined the focus further and led me to identify opportunities to integrate textile and non-textile materials and production processes in future work as well as to streamline ‘mesh and membrane’ constructions into a single system.

CHAPTER 05

Chapter 5: Entwined thinking, enfolded practice

This chapter explores current discourse on design thinking, investigating both similarities and distinctions between disciplines with particular reference to relationships between textiles and architecture. It then outlines how architecture's use of textile materials as self-organising systems has informed my silk-screen printing practice and my conception of the potentials of the samples created.

Design thinking and disciplinary difference

The principles of 'design thinking' are increasingly being applied to problem solving and process development in areas such as business; an approach advocated by Russell Ackoff (2010), who values its holistic perspective where unexpected outcomes are opportunistically prioritised to structure and resolve problems simultaneously. However, in trying to identify the common elements of creative design practice Cross (2007) has tended to downplay the disparate practices of distinct design disciplines. When explicated as a single unified entity the multitudinous design disciplines can become homogenised and over generalised. Despite overarching common elements there is still a great variety of method, thought and outcome across the design disciplines.

Wang and Ilhan argue that design is distinct from the sciences and humanities not because it possesses a common body of knowledge unique to the discipline as a whole, but because it draws on and synthesises all extant bodies of knowledge as appropriate to the specifics of a particular design practice. They assert, "design knowledge actually draws from the general pool of cultural knowledge for the purposes of informing creativity." (Wang & Ilhan 2009, p.19) They propose that the creative act of production is the unifying factor of the design disciplines, rather than a specific body of knowledge. This perspective acknowledges disciplinary difference while still recognizing common elements of design practice.

In Wang and Ilhan's model of design thinking distinctions between design disciplines are differentiated by gradated and overlapping degrees rather than the total disconnection of absolute difference, as with the distinction between the arts and sciences previously discussed in chapter two. For example, while architects might prioritise knowledge from domains such as mathematics and engineering, printed textiles designers may rely on areas including mathematics and chemistry.

Textile approaches

The mathematical underpinnings of textiles are clear. Textile designers apply principles of proportion, symmetry and tessellation as a matter of course when devising the structures of repeating pattern across textile lengths. Textile techniques and artefacts have been used to manifest complex mathematical principles physically, a fine example being the crochet hyperbolic coral reef exhibited at the Hayward Gallery and on the South Bank in 2008 (fig 76). It has been suggested that these physical textile patterns precede the abstract analysis that leads to mathematical principles.

> "Gerdes writes that the regularity of plaited products teaches humans to recognize patterns and to use them afterwards for geometrical forms, art, and mathematical analysis." (Kraft 2004, p.281)

The jacquard loom's punch card operation is commonly recognised as the conceptual precursor to the binary structure of computer programming. However, while in the mathematical arena numerical sequence, pattern and repeat are made explicit, in the textile arena the numerical aspects underpinning the work are often hidden and experienced at a more instinctive level. Ian Stewart (2010) notes we are able to carry out many maths based activities without explicitly understanding the mathematical coding that makes them function. The mathematics of textiles is practical not theoretical.

Similarly chemistry has given the discipline of textiles synthetic substrates with diverse properties that have transformed both fabrication processes and outcomes. Polyester's transformation of shibori practice has been described in chapter three. Chemical advances allow for the increasingly sophisticated colouration and finishing of fabrics, with many textile practitioners relying on chemical reactions to create particular functionalities or aesthetics e.g. the distressed, oxidised surfaces of Arantza Villas (fig

Fig 76. Hyperbolic barrier reef, South Bank Centre, 2008. Photo taken by the author.
Fig 77. Chemically distressed, 'rusted' textile, Arantza Villas.

77). However, designers often only know what effects these reactions will create and how to produce them rather than having a clear understanding of why the various chemicals interact in the ways they do. This limited comprehension of underlying theories does not necessarily compromise their practical use, fostering instead an attitude of open experimentation to seek out desired results.
In textile design the theories of mathematics and chemistry are applied flexibly and almost intuitively to real situations, yielding to unpredictable materials and subservient to wider concerns. Krappov states,

> "In order to gain life, ideas must travel from their roots in abstraction to the sights, sounds, smells and textures of the world of experience. Here is where designers enter the picture as co-equals." (Krappov 2001, p.453)

The intuitive, emotional, personal interpretation and practical application of domains of knowledge such as mathematics, chemistry and aesthetics by textile designers produces hybrid, particularly 'textile' outcomes that can shed new light on the knowledge domains from which they were born.

Distinctive disciplinary modes of thinking filter and organise information in ways that reflect their cultural values. However, I maintain that not only the domains of knowledge prioritised but also the materiality and making processes of a discipline influence the conscious and sub-conscious thought processes of designers practicing within it. Sensitivity to the materiality and microstructure of textiles is key to textile design. The inherent properties of textile fibres and their processes of manufacture are inextricably interwoven. To create textile substrates yarns and fibres must be flexible enough to bend and twist around each other yet stable enough to maintain their form.

Non-woven fabrics bond un-spun filaments together, entangling the fibres mechanically, thermally or chemically. Generally this makes fabrics that are inelastic and less strong than woven or knitted substrates that twist or knot long continuous threads to create the surface. However non-woven fabrics are cheap to manufacture, can be easily adapted and engineered to suit specific applications and as they are often uniform in structure and therefore non-directional they can be useful for the generation of designs using multi-directional folding.

The sequential, physical arrangement of yarn in both knitted and woven textiles produces repeating visual patterns that simultaneously form the structure of the material (Kraft 2004). Variations in patterns of construction produce differing behaviours. Close inspection of woven substrates reveal the repeated linear placement of warp and weft creating an interrelated system of undulating threads that becomes planar. These interconnected fibrous systems can be made up of elements that are individually weak, only becoming strong when incorporated into a single cohesive structure where, "The strength lies in the twist, not in the materials" (Laithwaite 1994). Woven fabric softens when freed from the tension of the loom, juxtaposing rigid and non-rigid qualities, as regimented framework becomes flexible form.

> "Cloth, woven on a loom, incarnates the most troubling of paradoxes. It is a grid, a matrix of intersecting verticals and horizontals, as systematic as graph paper, and yet it is soft, curved and can drape itself into the three-dimensional fold." (Pajaczkowska 2005, p.233)

Using contrasting structure but to similar effect, the knitted substrate systematically and symmetrically loops a single linear yarn to form planar surface, its meandering thread imparting an even greater degree of elasticity than the straight structure of weave.

Variations in structure and material composition at micro scales alter the texture, aesthetic and functional properties of planar textile surfaces and the behaviour of any subsequent layers applied to this base. Printing and laminating onto textile substrates superimposes one pattern over another. Sensitivity to these constantly changing tensions is essential for the successful production of textile artefacts. Whereas the practical work discussed in chapter three predominantly used woven substrates to create the stability needed for origami-folded designs work described below exploits the extreme elasticity of knitted textiles to create different behaviours and effects.

Silk-screen printed textiles, like those discussed below in 'Printing the Fold', rely on a pliable mesh to ensure the even deposition of ink onto the stretched cloth beneath, a transfer of the dyestuff from one textile surface to another. However, the ductile materials of textiles have a propensity to 'creep', leading to uncertainty of outcome or, in the case of silk-screened fabrics, imperfect alignment. This illustrates the flexible, changeable materiality of textiles, where unintended or unforeseen consequences are almost certain and continuity and coherence is achieved through a succession of transitory states. This constant motion of the material creates a 'nomadic relationship of points' (Eisenman 2004, p.41) that echoes the conceptual reconfigurations of folded thought discussed previously in chapter 2, and perhaps contributes to an explanation of particularly textile ways of thinking.

Barnett (1999) and Lomax (2000) drawing from Serres further explore the advantages of the 'soft' logic described in chapter 2 using the textile metaphor of 'sack' versus 'box' thinking. While numerous pliable large textile sacks can be folded into a smaller sack a large rigid box cannot be placed into a smaller one. 'Box' thinking represents an active process driven by clearly defined concepts that leaves little room for doubt or uncertainty, its rigidity seen as rigorous. 'Box' thinking is measurable, amenable to precise mathematical prediction and practically applicable. 'Sack' thinking is not so easily quantifiable or capable of straightforward explanation. A mathematical model of the complex behaviour of sacks folded within sacks can only describe a range of possible outcomes and, due to the unpredictable creep of the physical textile, does not replicate, in detail, the particular outcome that occurs in reality. Ingram (2010) points out that mathematical modelling uses selected data, filtered and interpreted by the modeller. Real systems can include unknown elements, such as the factors governing textile creep, that are then omitted from such virtual models. This incompleteness in the mathematical model means that only general outcomes, not specific details, can be predicted at the outset. This situation is illustrated by the unpredictable emergent behaviour of the textile systems discusses below in 'Disciplinary cross-pollination: the mutual influences of textiles and architecture'. It could be argued that working with the unpredictable complexity of textiles leads to the adoption of modes of thought which value malleability, connectivity and continuity above the precision and division of Cartesian logic.

The ambiguity of textiles creates a connecting thread between the abstract and the concrete. A textile designers bond with the stuff of textiles is more profound than just the understanding and conceptualisation of physical behaviours. I suggest that our intimate and ubiquitous daily bodily contact with textiles fosters a particularly close relationship between textile designers and the materiality of their discipline.

> "Because clothes make direct contact with the body, and domestic furnishings define the personal spaces inhabited by the body, the material which forms a large part of the stuff from which they are made – cloth – is proposed as one of the most intimate of thing-types that materialises the connection between the body and the outer world." (Attfield 2000, p.124)

Our experience of textiles is sensory, felt and lived as much as conceptualised (a fuller discussion of tactility and textiles follows in chapter 5). Thus the significance of the textile artefact reaches beyond its physicality to enfold matter, sensation, memory and symbol into a single entity. It jumps, to borrow from Bergson (2004), "from feeling to concept and the inverse". This embodied apprehension of textile materials perhaps explains the intuitive practical application of theoretical domains of knowledge in the textile design process.

Textiles create an indistinct interface between the fabric of our skin and the 'other' of the world, dissolving the boundary between material and concept as well as between disparate disciplines. Surat Maharaj identifies textiles as:

> "An 'undecidable' – as Derrida puts it, something that seems to belong to one genre but overshoots its border and seems no less at home in another." (Maharaj 2001, p.7)

That textiles wriggle out of precise definition should be valued not derided. Pennina Barnett (2009) suggests that this contributes to the "edginess of textiles", their indeterminate nature creating a network of strands that link different disciplines.

Disciplinary cross-pollination: the mutual influence of textiles and architecture

The interface between disciplines when explored and exploited by inter-disciplinary practice provides the gap in which to situate original knowledge. By crossing disciplinary boundaries you remove yourself from familiar settings. Placing yourself in foreign territory enables a re-framing of information and output as well as an element of purposeful de-skilling. By investigating styles of thinking prevalent in other disciplines one is able to question one's own habitual and cultural frameworks. Likewise practitioners scrutinising textiles from a position outside the discipline can offer new insight on routine practice.

The flexibility and ephemeral nature of textiles contrasts markedly with the rigidity and relative permanency of architecture yet, as many writers including Klassen (2006) and Houze (2006) observe, Gottfried Semper declared that architecture originated in the textile arts. Semper asserted that textiles were integral to the creation of the first manmade shelters, with minimal cloth walls demarcating space in a physical and symbolic separation of interior and exterior areas. Textiles are used today in architecture not only as physical materials for applications such as roofing, acoustic control and moulds for concrete but also as a metaphysical and theoretical framework. Textiles on a material level can dramatically alter our experience of space, e.g. softening the acoustics of an echoing chamber or warming surfaces to the touch. The use of textiles in architectural environments can make grandiose and intimidating structures more intimate, with haptic appropriation a key method of developing a feeling for such spaces. However, the impact of textiles on architectural practice goes beyond its surface materiality. Houze notes the process of designing buildings increasingly utilises the concept of 'textile' as a driving force or ' structuring principle'.

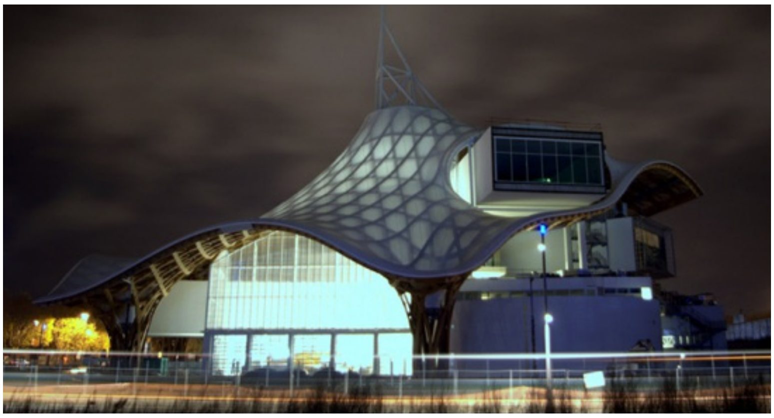


Fig 78. Money Zone, Millennium Dome, London, Amalgam Architects, 1999.
Fig 79. Pompidou Centre, Metz, Shigeru Ban, 2010.

Connections between these two disciplines have been explored by many, including Quinn (2003), Garcia (2006) and Hodge et al (2006). My own observation of architectural practice has shown that textiles are increasingly becoming removed from their low-tech antecedents, being placed prominently in modern constructions married with hard materials such as steel, glass, concrete and wood. This could be seen as the feminisation of a historically masculine discipline, yet this is perhaps an overly stereotypical conception. Textile materials can symbolise comfort, domesticity and intimacy, attributes often conflated with femininity yet this perception overlooks their diversity. Textiles can be so fine, diaphanous and fragile as to be barely there; the legendary shawl that can pass with ease through a wedding ring. Textiles can be rugged, rough, stronger than steel and so stiff they barely bend. The high functionality of increasingly technical textiles is being embraced in architectural contexts with exciting results. Depending on their composition and deployment, architectural textiles can take on the hard characteristics of the substances with which they are paired (fig 78) or have the power to soften and add a sense of intimacy to tough industrial materials (fig 79).

Textile substrates, whether knitted, woven or non-woven, achieve their state of being by unifying a multitude of disparate threads or fibres into one continuous surface. This drawing together of multiple elements creates an emergent system that displays unique, irreducibly complex behaviour particular to its scale, structure and materiality, which could not be predicted by experimentation using alternative materials or scale models. By harnessing this emergent behaviour as a dynamic organisational strategy in the design process one can generate novel, non-Euclidean forms that merge surface and structure.

Architect Frei Otto's pioneering work has highlighted this propensity of textile fibres and threads to create malleable, interconnected, textile networks determined by their very materiality. Since the 1940's he has used textile systems both as calculative tool for the development of tensile structures as well as for the buildings themselves (Glaeser 1972). Using natural form as a behavioural rather than morphological model, his novel approach to designing buildings was a huge departure from the then common reduction of architecture to elementary geometric forms. Primarily concerned with structural efficiency and drawing on his aeronautical experience he has carried the procedure of stretching a taut skin over a light skeletal structure from that discipline to architecture, leading to "the revival of the tent as a feature of modern architecture" (Jefferies & Wood Conroy 2006, p.234). Such textile architecture re-conceptualises micro scale textile models at macro dimensions and is based on the synergy between the components that make up the whole structure rather than on the behaviour of its parts in isolation. This echoes the synergy D'Arcy Thompson saw in natural structures where,

> "…the beauty and strength of the mechanical construction lie not in one part or another, but in the harmonious concatenation which all parts, soft and hard, rigid and flexible, tension bearing and pressure bearing, make up together." (D'Arcy Wentworth Thompson 1917, pp.224-225)

Gaudi, reflecting D'Arcy Thompson's assertion that the shape of an object is a physical diagram of the forces acting upon the matter of which it is made, hung chains between points to create catenary curves. He then inverted these tension models, making compression models for architectural forms. Since the 1950s Otto has used textile materials in a similar fashion to create dynamic tension models that display emergent behaviour. By connecting pins with taut thread lines, slackening these threads and then dipping them in water or liquid soap, he exploits the self-organisational capacity of the materials to describe the most structurally efficient form (Spuybroek 2005) (fig 80-82). Building on D'Arcy Thompson's investigation of surface tension in the natural world with his experiments with thread and soap bubbles Otto developed his theory of minimal surfaces, demonstrating how "conceptual analogy can be linked with technical strategy" (Lim 2009, p.18). These models, when reiterated at larger scales using alternative materials, create lightweight buildings that provide maximum volume coverage with a minimum of construction materials.

> "Otto's concern with flexible surfaces not only blurred the classic distinctions between surface and support, vault and beam (suggesting a non-elemental conception of structural functions) but also make construction and structure a function of movement or, more precisely, a function of the rigidification of soft, dynamic entities into calcified structures such as bones and shells." (Mertins 2004, p.360)

A more recent example of such form finding practice is Spuybroek's World Trade Centre model, in which 16 wool strands hang from a horizontal plane (fig 83). Once the wool is dipped in water it becomes intertwined and interdependent, creating a 'virtual' straightness where the system as a whole is straight but its individual elements are not. Mertins notes,

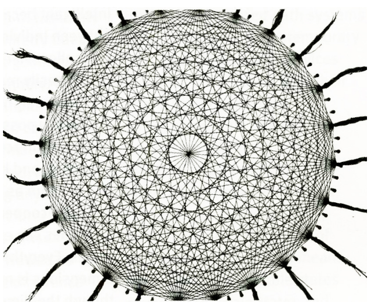
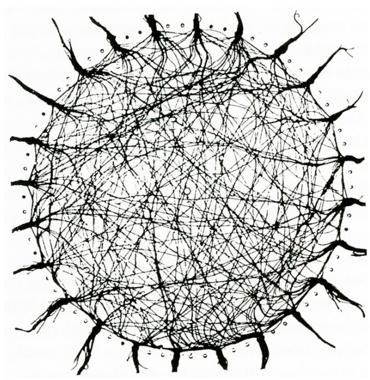
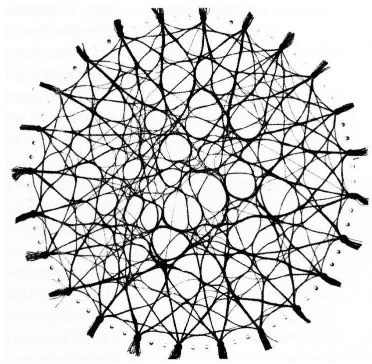




Fig 80. Frei Otto textile system, Step 1, connecting multiple points with thread.
Fig 81. Frei Otto textile system, Step 2, slackening threads to create detours.
Fig 82. Frei Otto textile system, Step 3, threads dipped in water self-organise to create optimised system.

> "Spuybroek [as well as Otto] is fascinated by the ways in which complex surfaces in nature result from the rigidification of flexible structures, a process so intricate as to elude precise theoretical or mathematical analysis." (Ibid, p.368)

The rigidification of flexible textile materials is fundamental to the creation of the structural planar forms of this project. My use of origami and shibori folds to create structural surface exemplifies this strategy. However, this architectural use of active systematic forces to create stiffness in flexible materials, inspired by natural generative models, suggests alternative approaches.

Although architectural models generally use textile threads, with soap bubbles or water prompting the self-organisational behaviour, the inherent properties of textile surfaces can also be exploited in similar ways. For example Philippa Brock's 'Self Assembly' collection (Brock 2008) uses high twist yarns that contract once wetted to create self-folding pleated surfaces (fig 84). Similarly, surface adjustments created by printing, bonding and lamination allow the substrate to function simultaneously as structure and self-organising system, properties that can be exploited in the design of folded textile structures. Through the considered application of 2-D motif the properties of elastic or layered bonded substrates can be used to directly manipulate the 3-D form.

Otto and Spuybroek's strategies for systematic optimisation of structures are reminiscent of Buckminster Fuller's concept of 'ephemeralization', which observed the efficiency of the natural world doing more with less, incorporating principles of multi-functionality. This adoption of biological paradigms demonstrates a "reconfiguration of the concept of 'nature' within the discourse of architecture; a change from metaphor to model" (Weinstock 2008, p.26). Observation of multifunctional, dynamic and adaptive biological systems has provided inspiration for textile as well as architecture design.

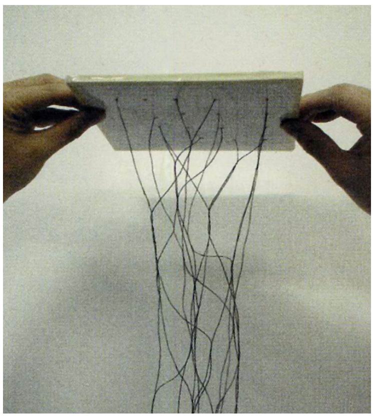
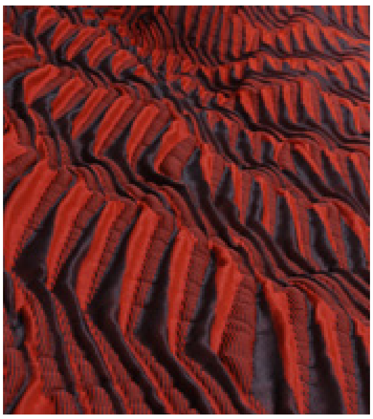




Fig 83. World Trade Centre thread model, Lars Spuybroek, 2001.
Fig 84. Jacquard woven silk, polyester/Lycra from the 'Self Assembly' series, Phillipa Brock, 2008.
Fig 85. Sculpted rayon velvet, Isobel Dodd, 1996.

Professor Julian Vincent, in collaboration with textile designer Dr. Veronika Kapsali has harnessed dynamic textile systems to replicate the shape deformation of pinecones in response to changes in humidity. They created a double layer laminate textile that is responsive to increased levels of perspiration. One layer is hydrophobic the other hydrophilic, creating different absorption rates that causes pores in the fabric to curl open when damp (Vincent 2006). Working on similar principles, gel polymer actuators trapped in braid can do mechanical work such as lift weights (Bonser 2006). Comparable mechanical solutions could be used for the reversible self-activation of my origami folded fabrics. However as the direction of the fold varies from upper to underside throughout the pattern, a series of pertinently placed printed dots at hinge points might be more effective than an unvarying laminated layer for the creation of environmentally reactive textile systems. Such a solution would not only be cheaper, minimising the use of expensive materials, but would also enable local adjustments to the behaviour of the substrate.

Architect, Lars Spuybroek has adopted the physical ‘textile systems’ of Frei Otto and evolved them conceptually, teasing out the thought processes underlying such textile modelling. Spuybroek abstracts ‘textile systems’ into ‘textile thinking’, which he describes as a continuously linked thought process, useful for creating the conceptual cohesion of disparate elements, processes and behaviours. Applying both ‘textile systems’ and ‘textile thinking’ to his architectural practice he explores the design potential of continuous, complex, flexible systems where relationships between elements create emergent systems and forms more important than any individual part (Spuybroek 2006).

This elucidation of the methodological value of textiles by another discipline not only validates textile approaches but also reframes textile practice within the culture of architecture, subtly recasting it with a different emphasis. The work of people such as Otto and Spuybroek highlights aspects of textile practice not generally articulated by textile practitioners, e.g. the interconnected nature of textiles and the role of their material systems in governing form. Spuybroek’s emphasis on the continuity and emergence of connected ‘textile’ thinking echoes the philosophies arising from metaphorical textile folding discussed in chapter two and has prompted the re-evaluation of my textile practice from a different perspective.

Printing the fold

Printed textile design is traditionally concerned with surface appearance, its applied, decorative motifs commonly seen as a façade or superficial embellishment not integral to the substrate. However, many dyes penetrate the substrate in a molecular chemical reaction that integrates print and surface, although such printed interventions are seldom used to change the form or shape of the material. Textile textures are commonly transformed with flocking materials, foils and lacquers that adhere to the surface of the substrate, yet these treatments generally create only flat or low relief effects. I have drawn on my empirically gained knowledge of the reaction between substrate and print medium to unify motif and structure, further developing processes that create 3-D form established by designers such as Isobel Dodd and Reiko Sudo.

Isobel Dodd's printing of simple latex spots onto elastic substrates exploits the same principle as Otto's 'minimal surfaces' created with yarn and soap bubbles (fig 85). The fabric is kept under tension whilst printing, being released once the latex has cured. The printed areas provide rigidity while the unprinted substrate retains its elasticity. The relationship between the elastic and non-elastic areas governs the resultant structure, the opposing tensions forming curves that deform the 2-D plane into a 3-D form.

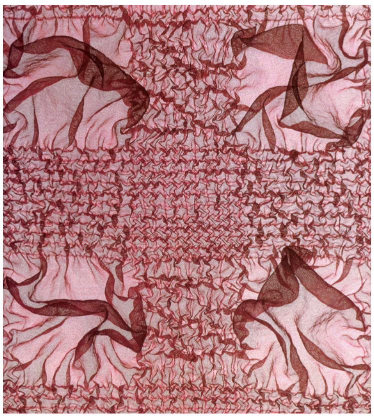
Reiko Sudo exploits the incompatible shrink rates of industrial materials bonded by printing to ordinary fabrics to create the controlled texturisation of her 'Jellyfish' fabric (fig 86). Often her fabrics are first produced with hand techniques, which are then developed and adapted for production. Here a PVC textile mesh commonly used in the Japanese brewing industry has been temporarily bonded to a 100% polyester fabric with a silk-screen printed adhesive pattern. The resultant layered textile is then heated causing the mesh textile to shrink to 50% of its original dimension, leaving the polyester layer permanently moulded into its new three-dimensional form (McCarty & McQuaid 2000, p.25). The high temperature causes the PVC mesh to degrade facilitating separation from the polyester. The exploitation of incompatible shrink rates in layered materials can be applied to many material combinations.

By creatively adapting standard 2-D textile print processes to exploit the form-finding capacity of textile systems I have been able to maximise the transformation of 2-D planar surface to 3-D planar form. In the initial range of printed experiments undertaken, key examples of which are outlined below, regularly repeating and predominantly organic motifs were printed onto tensioned and non-tensioned substrates in an intuitive, un-conceptualised use of the self-organisational capacity of textile substrates. The first printed samples used a 3 parts to 2 mix of Bricoprint puff binder, which irreversibly expands to several times its original dimensions when heated, and opaque white binder on a range of substrates to manipulate the surface.

❖ Sample 6 used this medium to bond a double layer of silk mousaline to highly tensioned cotton lycra (fig 87). I combined Dodd's opposing tensions with Sudo's incompatible shrink rates to exploit the significantly different elasticity of the two bonded fabrics. The printed areas set the lycra at its full extension while the unprinted regions retained their elasticity which, when released after printing, pulled the sample into a well-defined 3-D relief texture. The cream hued mousaline layer folded to give an interesting, blistered texture to the unprinted areas and harmonised the sample colour. However, although the binder stiffened the fabric enough to create defined 3-D form it imparted an unpleasant rubbery handle that detracted from the overall aesthetic quality. Additionally, the fabric layers were not bonded securely and could be pulled apart relatively easily. Further tests were needed to find a more suitable printing medium. However, ultimately an error prompted the developments that led to a solution to these problems.

The many stages of preparation in the printing process limit the spontaneity of the activity yet accidents can provide fortuitous and impromptu opportunities. I initially intended to foil ❖ sample 7 however I mistakenly substituted the flocking adhesive 'Tubvinyl 235MC-3' for foiling adhesive, not realising my error until the motif had been silk-screened. Without a comprehensive background knowledge of both process and material recognition of this opportunity might have been lost. However, aware of the substitution I could appreciate that printed onto stretched lycra the unmixed adhesive created a series of pronounced domes similar to ❖ sample 6 on release of the tension, though the resultant fabric was much more pliable and had a softer aesthetic than its puff binder predecessor (fig 88). The adhesive set the lycra in a stretched form that gave a slightly translucent appearance to printed areas, which was particularly noticeable when the sample was backlit. Being clear, the adhesive gave no problem of incompatible colouring.

This accidental discovery led to the creation of ❖ sample 12 in which standard flocking techniques are used to bond silk mousaline to stretched cotton lycra. The layered cloth is subsequently released leaving an undulating 3-D relief form that resembles a double weave construction (fig 89). The fabric remains pliable and has a soft velvety texture yet holds its shape well in flocked areas without the stiffness and unpleasant handle of its pigment paste counterpart. The fine striations of the unprinted mousaline layer contrast with the downy, flocked areas enhancing the feel of the fabric in an aesthetically pleasing manner. The flocked areas strongly adhere the fabric layers making them difficult to separate.



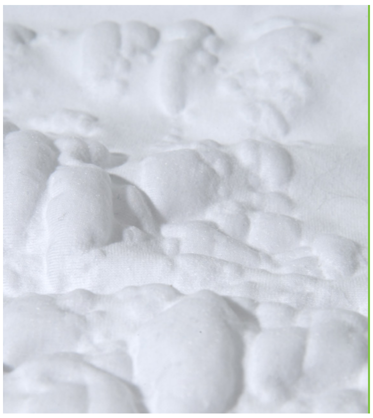


Fig 86. 'Jellyfish' polyester fabric, screen-printed and flash heated, Nuno, 1993.
Fig 87. Printed cotton/Lycra, silk mousaline, sample 6, 2005.
Fig 88. Printed cotton/Lycra, sample 7, 2005.

As my print experiments progressed I consciously began to exploit the form-finding potential of the dynamic material systems encountered, informed by my growing awareness of architectural practice using such strategies. I evolved motifs to create the optimal 3-D transformation of the substrate, using puff binders as well as foiling and flocking in unconventional ways to alter the behaviour, handle and structure of the substrates (❖ samples 21-39). These printing techniques relied on the active relationship between treated and untreated areas to produce hard and soft folds across the textile surface, delineating the form of the samples created. The fold type created was dependent on the motif and printing mediums used as well as on the elasticity and weight of the substrate.

Endeavouring to achieve the more robust form given by puff binder yet improve the aesthetic of the printed regions I began to use the puff binder as an adhesive for flock and foils instead of proprietary bonding pastes (❖ samples 24, 28-34). Foiling was adhered by placing the foil face down underneath the tensioned fabric before printing and finishing. The print would soak through the fabric enough to fix the foil superficially. A secure bond occurred as the puff binder expanded, pressing firmly into the foil. Attempts were made to press foil into the wet surface of the print from above to create double sided effects but the results were inconsistent. I tried printing a layer of the proprietary adhesive over the puff binder, foiling in the conventional manner but the action of peeling away the plastic film that supported the foil tended to lift patches of the printed areas, spoiling the finish (fig 90).

Flocking directly into the wet puff printing medium and baking to set the effect deposited a substantial, stiffening layer that produced significant structural effects on highly elastic fabrics. However, its efficiency as an adhesive was significantly reduced as colour pigments were added to the paste, leading to samples shedding flocked fibres. In an attempt to enhance the structural properties and aesthetic of the printed areas further I placed flocking paper on the underside of the substrate before printing. In

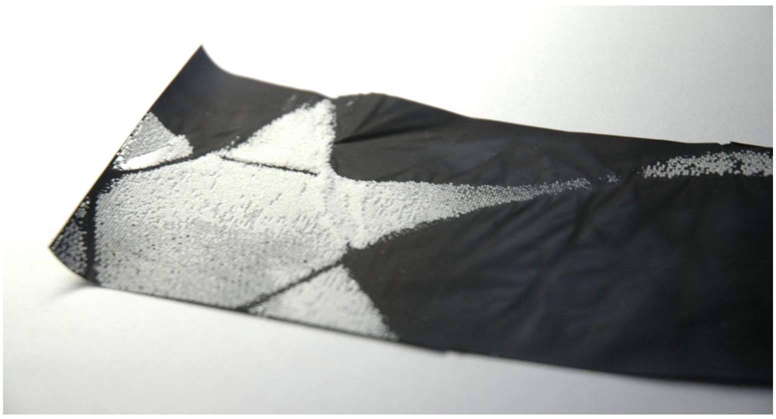


Fig 89. Printed and flocked cotton/Lycra, silk mousaline, sample 12, 2005.
Fig 90. Example of foil lifting the puff binder.

Fig 91. Printed and foiled polyester/Lycra, front of sample 34, 2006.

Fig 92. Printed and foiled polyester/Lycra, back of sample 34, 2006.

some cases the print paste would soak through enough to adhere them, making the fabric double sided. Yet as sample sizes increased the results became progressively more unpredictable.

The star motif used singly in ❖ sample 23 evolved through a number of iterations to form a series of sweeping arches when printed as a repeating pattern (❖ samples 24, 29, 31-35: figs 91-92: ★ film 3). However, the creation of larger samples highlighted numerous and sometimes unavoidable variations that occurred throughout the production process. Attempts to create double sided flocked effects at larger scales all failed, with only sparse patches of the paper flock adhering to the underside of some substrates. The stocking stitch knitted construction affected how the print soaked into the fabric. It became apparent after close inspection of samples 033-035 that when the print paste was printed on the reverse, subtly textured side of the substrate ink dispersed along the line of the knitted rows blurring the edges of the printed forms.

The knitted fabrics used were inherently elastic due to their construction and this elasticity was further enhanced by the use of lycra. As samples were hand stretched prior to printing it was difficult to obtain a consistent tension across the whole surface. The edges would tend to extend to a greater degree than the centre especially at anchor points. The need to stretch the fabric also severely restricted the piece sizes that could be made. The directional microstructure of the substrate affected the way in which the fabric self-folded when the tension was released, subtly skewing the regular repeating geometric motif once it achieved its 3-D form. The collapse of the arch centres in these samples that over time affected the whole fabric occurred much earlier when situated at certain orientations to the fabric grain.

In the subsequent evolution of my printed practice I explored the potential to create origami type folded textiles using the printing techniques developed. Whereas in previous print experiments both printed and unprinted areas folded to create form here movement was limited to untreated regions. I printed origami nets onto lycra, nylon, cotton and polyester substrates to stiffen the planar areas of the design sufficiently to remain static whilst leaving unprinted channels to act as hinges. This meant design could be folded without requiring the paper moulds necessary for the heat-set origami samples (described previously in chapter 4), allowing the production of larger piece sizes.

❖ Sample 25, the first attempt was unsuccessful as I failed to separate the substrate from the backing cloth before applying the flocking. Once dried the adhesive would have formed a permanent bond between the sample and the backing cloth but my endeavours to part them disturbed the flocked layer and critically compromised the structural capabilities of the printed areas. Repeating the experiment using a more substantial polyester lycra and separating the lycra from the backing cloth before flocking produced better results (❖ sample 30: ★ film 2: fig 93). The elasticity of the substrate and its tension when folded ensured that the origami form held in place once folded. However, unheated the sample had no shape-memory capabilities and if opened the fabric required complicated refolding. Heating the folded fabric with a domestic steam iron imparted shape-memory properties that allowed the sample to be opened and closed but caused a slight buckling of the printed regions.

In order to widen the potential uses of these printed origami fabrics I progressively attempted to enlarge their scale whilst retaining their shape-memory capabilities. For ❖ sample 37 I applied red flock to a woven, non-elastic polyester substrate in a pattern devised to create a gently curving surface comprised of repeating double-sink folds. The scarlet sample had a smooth velvety texture and a striking aesthetic although in some areas the puff binder had bubbled, spoiling the even finish (figs 72 & 94). I baked the sample in a dry heat to set its form but ultimately the printed areas were too heavy to be supported by the substrate, causing the shape to drop out unless supported. I could have stitched the sample at key points to secure its shape but the textile would then loose its crucial transformable aspect. I had to find a more substantial base fabric if I wanted to increase the size of the folded units yet still retain the mobility of the design.

Enlarging the repeating double-sink design to twice its previous scale I applied it to a cotton plain-weave shirt canvas (❖ sample 36). After finishing the puff binder and flock by baking in a dry heat the major mountain and valley folds were ironed into the design. The fabric was then manipulated into its final form, being held with clips at key points for several days before releasing. This robust material was stiff enough to support the weight of the flocked design but, being cotton, would lose any shape-memory if wetted. Additionally, the flock did not adhere evenly to the surface and continued to drop heavily, leaving an unattractive balding surface.

Fig 93. Printed, flocked and origami folded polyester/Lycra, sample 30, 2006.
Fig 94. Bubbling at edges of printed and flocked polyester, sample 37, 2007.
Fig 95. Printed, glittered and origami folded cotton, sample 39, 2007.

Using the same substrate and screen-printed design I intended to apply foil to ❖ sample 39 and printed grey puff binder as a base layer to compliment the gunmetal grey, metallic foil. However, my previous practice of laying the foil underneath the fabric before printing the puff binder through to adhere the foil to the substrate proved to be unsuccessful with this batch of samples. This may have been due to the fact that these non-elastic samples had to be lifted from the print table before heat pressing whereas previous elastic substrates had remained undisturbed, stretched onto boards until the finishing processes had been completed. It is also possible that the cotton fabric was too thick to allow sufficient penetration of the print paste for the adhesion of foil placed underneath the substrate. As all previous attempts to apply the foil to the top of the printed areas had been unsatisfactory I decided to apply glitter to the surface instead (fig 95: ★ film 5)).

I printed the appropriate proprietary adhesive on top of the dry, unexpanded puff binder layer before sprinkling polyester glitter flakes over the wet adhesive. The sample was left overnight to dry thoroughly. Patchy adhesive coverage led to an uneven coating of glitter. Unavoidable movement and rolling of the fabric prior to baking exacerbated this, further abrading the glitter layer. Expansion of the puff binder during the fixing process may also have opened gaps in the adhesive layer or weakened the adhesive bond causing a continuing fall of the glitter. However, the resulting thinner coverage gives an interesting 'emery paper' appearance to the final fabric.

The fabric was ironed and clipped into shape, as in the previous sample. At the moment of its release the fabric maintained a tight, curved tunnel structure. However, within 24 hours the piece had succumbed to gravity with the open ends drooping down the sides of the plinth. This creep continued over the course of two weeks, meaning that the starting and final shapes were very different to each other. This fluidity of form was not intended or predicted but prompted consideration of how this 'creeping' property of the form could be beneficial or desirable, as well as exploration as to how a stable final form be achieved.

Each folded unit of this design was larger than anything I had produced before but was still relatively small scale in relation to the human body. To test the viability of significant further enlargement, to shift the emphasis of potential application from on the body to around the body I attempted to fold a two-unit double sink fold on a much larger scale using stiff paper (fig 96). The physical experience of folding such a large piece, approximately 130 x 260cm, brought different challenges to working on a smaller scale. Significant perceptual changes occur through the enlargement of the folded unit. The relationship of the object to the human body is transformed, becoming a much more tangible and engaging physical presence. Although the folding can be less precise without compromising the overall structure it is much more difficult to align edges with accuracy and ultimately I think that to realise larger folded structures with any degree of success I would have to enlist the help of at least one other person to manage the material manipulation.

The paper, although reasonably heavy in weight (the exact gsm is unknown as it was a found material) remains quite flexible even once folded into its final form and is extremely susceptible to tearing at points where multiple folds intersect. My current methods of subverting standard textile printing process to create material stiffness wouldn't achieve the stiffness necessary to create stable folded form at much larger scales. Similarly, the substrates used do not demonstrate the necessary form holding capacity. In order to realise similar folded designs at larger scales such as these a different approach would be needed. The lamination of plastics or foams to fabrics in key areas could potentially create variable stiffness sufficient to form a viable self-supporting structure.

Changing approaches

My intention at the outset of the research had been to refine the 3-D textiles generated throughout the research into a few select working prototypes, evaluating the suitability of potential applications through further practical experimentation and testing as well as reflection on contextual research. However, the selection of prototypes would have necessitated a narrowing of scope that did not feel appropriate. I had initially thought that my affinity with architectural practice indicated that I would create architectural outcomes but came to realise that in fact my interest lay with architectural approaches and the ways in which these might be usefully integrated into textile practice. My exploration of the form finding potential of self-folding and self-supporting textiles could be seen as a re-interpretation, from a textile perspective, of architectural interpretations of biological and textile models.

Textiles are commonly used as material for the construction of other things, often subservient to the designs superimposed upon them and not end products in themselves. Architecture's creation of dynamic textile models for the conceptualisation of form, function and future application allowed me to regard textiles from a different perspective, profoundly influencing my practice. It was a visit to the 'Psycho Buildings' exhibition at the Hayward Gallery in 2008, where fine art and architectural installations were shown together without distinguishing their differing origins, that I finally recognised that design maquettes can function in a manner reminiscent of fine art. Architectural models are not necessarily, as might first appear to those outside the discipline, models of actual buildings but can also be models of ideas of buildings or even models of concepts. Architects, like artists, create installations to challenge preconceived notions and to explore new ideas, not only to construct practical and functional structures.

While small-scale architectural maquettes and drawings are not uncommon in gallery contexts they are often presented as 'scale models' and 'blueprints'. Frequently large architectural models presented in open-air settings are labelled as 'pavilions', a term that could be considered to allude to the practical rather than artistic function the piece. These linguistic labels had for a long time directed my conception of such objects but it is likely that an architect wouldn't have had such a narrow understanding of these words. This demonstrates how varied interpretation of terms, constrained by conventional usage or refined through disciplinary knowledge, can influence thinking.

Considering my own textiles as experimental models, not as intermediary materials or concrete outcomes, gives me the freedom to juxtapose materials and forms that are not necessarily functional, to create conceptual sketches rather than working prototypes. These more open experiments can lead on to the development of more specific practical applications once a range of ideas has been 'played out'. The adaptable and self-supporting textiles created as part of this research have enormous potential when viewed as iterations that could be developed in numerous ways and diversely applied. Their interest lies in their multiple capabilities not in a particular application. To realise their full potential it was necessary first to cultivate this adaptability, creating a variable, customisable system for the design and production of these textiles and avoiding narrowing the focus to particular applications too quickly.

The use of folded textiles as metaphor for flexibility and continuity in philosophy has been discussed in depth in chapter 2. Deleuzian folds describe pliable, dynamic spaces yet, as Krissel (2004) observes, architectural readings of these folds remain static, theoretical and diagrammatical, due in no small part to the physical constraints of the discipline. The materiality of textiles, more ductile than that of architecture, is perhaps more suited to encapsulate the essence of the nomadic, active and adaptable folds of Deleuze. The malleable materiality of the discipline facilitates the creation of mobile, transformable forms. The potential application of these forms in diverse areas is assisted by already widespread acceptance and use of textile materials across many disciplines. Yet it is also important to preserve the pliable essence of conceptual folding in the processes and outcomes of this research, as such flexible 'textile' thinking could be seen as integral to the success of projects and practices that amalgamate different processes and behaviours, as well as disciplinary approaches.

This chapter has explored how textiles fit into current discourse on design thinking, considering how different disciplinary approaches impact on practical and conceptual development, particularly discussing overlapping methods in textiles and architecture. It has outlined how architectural practice has informed my considered exploitation of textile materiality to create dynamic self-folding systems through silk-screen printing as well as my reimagining of textiles as models that visualise future applications.

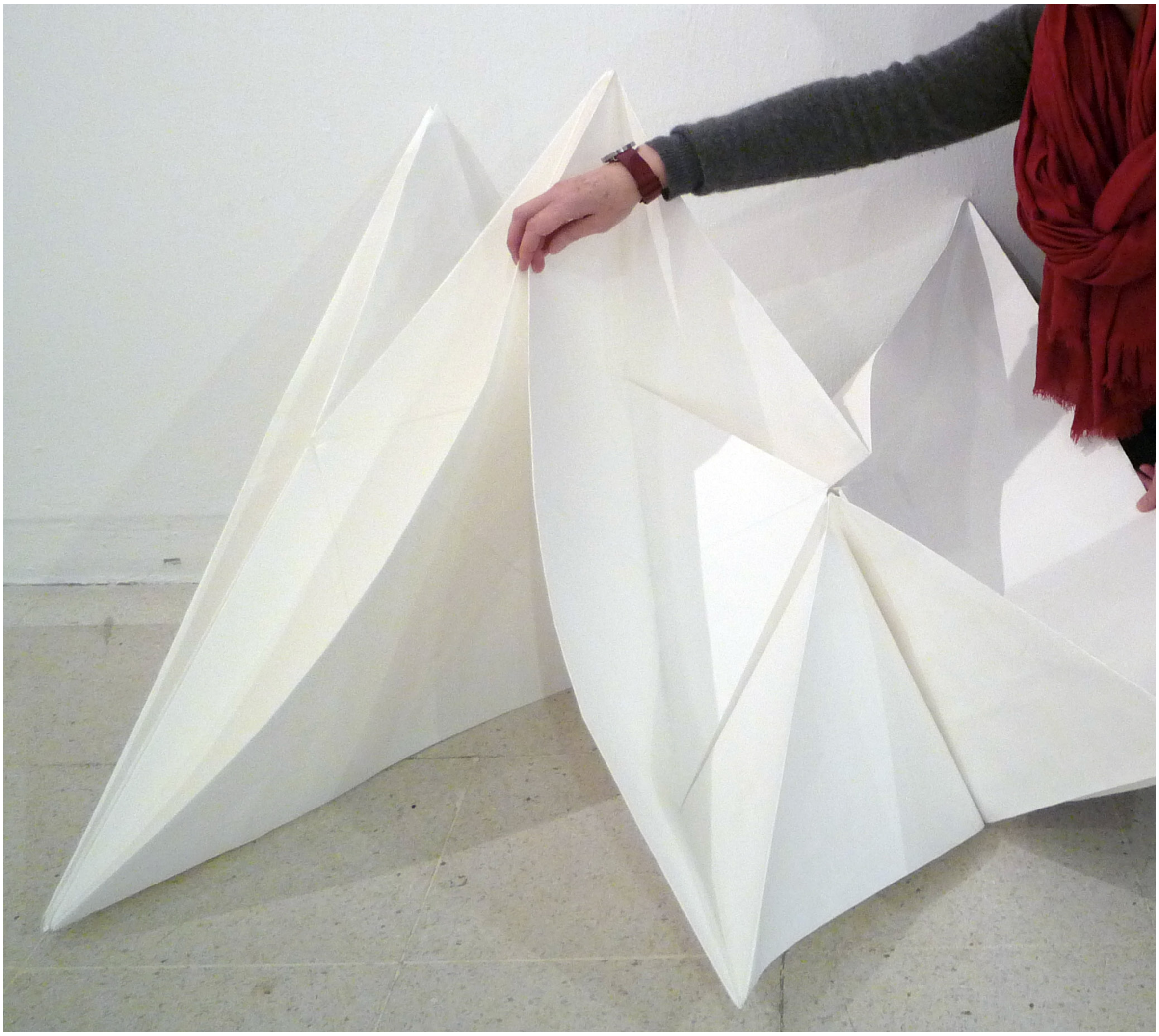


Fig 96. Large paper double sink fold.

CHAPTER 06

Chapter 6: Pliant process and embodied making

This chapter discusses the importance of touch in generating understanding of textile materials and making. It considers how opportunities presented by disembodied digital technologies can be exploited without detriment to this process of knowledge generation. It then describes practice using laser cutting, lamination and bonding techniques for the creation of larger-scale, self-supporting deployable textile structures.

Embodied knowledge: tactility and the intelligent hand

> "In the academic world touch has often passed under the radar. Like the air that we breathe, it has been taken for granted as a fundamental fact of life, a medium for the production of meaningful acts, rather than meaningful in itself." (Classen 2005b, p.2)

Historically Western culture has denigrated touch and other bodily knowledge, regarding it as a primitive lower form of knowing.

> "Aristotle…considered sight as the most noble of the senses 'because it approximates the intellect most closely by virtue of the relative immateriality of its knowing'." (Pallasmaa 2007, p.15)

The senses and sensuality are often conflated with pre-verbal stages of development, femininity and sexuality and as a result considered unsophisticated, irrational, emotionally driven and an embarrassing, slightly shameful aspect of our beings to be repressed (Howes 2004).

The denial of bodily knowledge as a valid and valuable way of knowing has led to a detrimental separation of hand and head where "both understanding and expression are impaired" (Sennett 2009, p.20). It is necessary to exist in and to interact with our environment on many non-visual levels before we can truly be said to understand its nature. As Benjamin points out,

> "the tasks which face the human apparatus at the turning points of history cannot be solved by optical means, that is, by contemplation, alone. They are mastered gradually by habit, under the guidance of tactile appropriation." (Benjamin 1999)

Whilst vision gives a detailed description of the surface features of our environment, a superficial mapping of the landscape, touch provides insight as to how these elements are interrelated. "Whereas topography is visual, 'topology is tactile'" (Connor 2004, p.323).

Attention to details of surface texture in the design process establishes the material, tactile object as central, rather than the image of the object. The surface is phenomenological, governing how the body relates to the object as well as the material, with definable performance characteristics. By managing the surface space of an object you can manage its interaction with the world. Other cultures suggest alternative hierarchies that may be more sympathetic to the tactile, emotive world of textiles. Kenya Hara states that his Japanese heritage allows him to "design outside of a consideration of form. Japanese design makes more of the issue of how something is felt or accepted." (Kinser Hohle 2005)

As discussed previously in chapter five, the sensorial aspect of materiality is prominent in the discipline of textiles. Textiles enfold us throughout our lives, embedded in our daily experience through their intimate, whole-body contact with our skin.

> "Textiles are a second skin, which prodigiously enhances our pleasure in the first." (Graves 2003, p.49)

Our understanding of textiles is mediated by touch in an interaction not limited to the hand. Touch makes us aware of our physical body and its interaction with others and the environment, a somatic intelligence that engenders a fusion of our surroundings and ourselves. There is no distance or separation between the touching and the touched. Through touch, one is "amidst rather than standing before the world" (Connor 2004, p.322). Creased cloth constantly leaves imprints on our skin, embossing its history on our impressionable boundary with the external world. This liminal folding plays a significant part in our development of embodied knowledge. Serres notes,

> "Consciousness resides in this contact… It is often hidden in a fold of tissue, lip against lip… a hand clenched into a fist, fingers pressed against each other, the back of one thigh crossed over the front of the other, or one foot resting on the other. I wager that the small, monstrous homunculus, each part of which is proportional to the magnitude of the sensation it feels, increases in size and swells at these automorphic points, when the skin tissue folds in on itself. Skin on skin becomes conscious…Without this folding, without the contact of the self on itself, there would truly be no internal sense, no body properly speaking, cœnaesthesia even less so, no real image of the body; we would live without consciousness; slippery smooth and on the point of fading away." (Serres 2008, p.22)

Our proprioceptive and kinaesthetic senses play a part in tactility as touch encompasses an element of motion, stroking and rubbing the skin against surfaces to stimulate our senses but touch working in isolation is an inaccurate sense.

It should be noted that although haptic experience is grounded in physical sensation the language of touch, like abstract and symbolic verbal language, is still ambiguous, subjective and open to differing interpretation. It is duplicitous; an identical touch can appear safe or aggressive, attractive or repulsive, intimate or alienating, nurturing or destroying to different individuals. Kozel notes, “When interaction is dependent upon one sense, it becomes inherently fragile.” (2005, p.444). Touch is evocative but not discerning, working more efficiently in combination with other senses.

The effect of synaesthesia and other less extreme overlaps between the senses encourages a whole body knowing of the material. This crossover of the senses allows one to feel an object without touching it. A vocabulary of touch builds up over our lifetime and is a cultural phenomenon learned along with language (Classen 2005a). Textiles imply bodily contact even if none occurs. Memory aroused by visual stimulus awakens haptic consciousness, as Pallasmaa says “Vision reveals what touch already knows.” (Pallasmaa 2007, p.42) Our senses co-operate to construct a complete physical and emotional conception of an object from the feelings that are generated in the body. Dorinne Kondo talking of the Japanese tea ceremony states, “The interaction of various sensory media creates a multiple layering of meanings that ‘all add up to one message’ (Leach 1976:41). Though there may be qualitative and significant differences among the various sensory modes…the gathering of these elements into a single ceremony tends to highlight the similarities among them.” (Kondo 2004, p.207)

This unarticulated whole body knowing is tacit knowledge, carried unconsciously within one but informing the activity of making. Hand making can be a repetitive process but slight variances of movement, pressure or temperature affect outcomes. No two hand made objects are exactly alike. Embodied tactile knowledge of material properties influence the forms created, the maker’s physical interaction with the materials leading to a metamorphosis of material through process.

In the making process the hand becomes intellectual, enabling the simultaneous creation and analysis of work. As discussed previously in chapter 3, observation of my own practice (★ films 1 & 2) shows my hands constantly, unconsciously adjusting and appraising the work. The hand is the most highly developed pre-lingual part of the body (Tallis 2003), acquiring sensual sensory knowledge through the manipulation of materials. Driscoll (2009) identifies two distinct ways the hand touches. Manipulative, functional touch, for example folding a towel or doing up a button, is a sub-conscious action that employs tacit knowledge while sensual touch consciously seeks out the feeling of the surfaces contacted, noting the pleasure or pain that such contact brings. Both types of touch combine in the making process, facilitating deeper understanding of technical limitations of processes and physical properties of materials. Sennett describes this as ‘material consciousness’ (2009, p.123). New sensual knowledge acquired throughout the making activity can over time become assimilated into one’s sensual vocabulary as tacit knowledge or practical wisdom.

Skill in making is attained through the integration of embodied knowledge with technical understanding, injected with imagination. Whilst consciously rationalised technical knowledge informs the preparation of the task, at the moment of making touch guides my actions allowing me to work intuitively to the strengths of the inherent qualities of the material. This could be described as “the intuition of the un-thought known” (Bollas 1987). Exploitation of the profound haptic knowledge of the materiality of textiles, gained unconsciously throughout our lives can significantly impact on the process of making. Being guided by touch is to put conscious action aside in favour of intuition and emotion.

Parallel folds: CAD/CAM in the making process

As technologies progress “artists and artisans are … embracing two opposites – hand and technology.” (Wada 2002, p.145). The progression of the textile design and making process to an increasing exploitation of digital technologies encompasses the challenge of changing an empirical craft to design engineering. Since the industrial revolution machine making has to a large extent removed embodied knowledge from the process of manufacture and more recently CAD/CAM has extended this disembodiment to the process of design. In what ways is it possible to reap the benefits of CAD/CAM technologies without losing important opportunities for innovation presented by embodied knowledge and hand making?

CAD/CAM technologies such as laser-cutting and laser-sintering enable the production of complex structures directly from 3-D computer modelled or scanned designs in ways impossible even just a decade ago. Technologies predominantly designed for use in engineering disciplines are drifting into

Fig 97. Design for Buddhist temple in Kagoshima, Japan. Laser-scanned folded fabric remodelled in another material, Thomas Heatherwick, 2005.
Fig 98. Laser sintered nylon textile, Freedom of Creation, 2004.

other areas as disciplinary boundaries blur. Designers are taking different approaches to the integration of such technologies into their practice.

Heatherwick Studios moves fluidly between CAD/CAM and numerous other means of design ideas generation and production (fig 97). As Heatherwick moves between product design, civil engineering and architecture he migrates his methods, re-imagining design and manufacture in an innovative way that creates what Sennet (2009) would describe as a ‘domain shift’. His process moves from hand drawn visualisations and physical modelling to digital modelling and making, followed by hand finishing. His use of a giant crane mounted CNC router to lathe out a smooth circular building from layers of pre-constructed concrete blocks is a visionary transfer of technology and provides an excellent illustration of the integration of digital technologies with craft practice to create innovation. Serres talks of the unification of body and tool in practiced use, the hand becoming the hammer it holds. (Serres quoted by Connor 2004, p.321) Heatherwick adapts digital technologies to function as a natural extension of his embodied practice.

The Dutch based company “Freedom of Creation”, headed by Kyttänen has exploited the potential of rapid prototyping technology to integrate design and manufacture into a single, streamlined process in which hand-crafting and embodied knowledge are completely absent. The disembodiment of these digitized designs is arguably reflected by their ‘other-worldly’ synthetic aesthetic. Designs are constructed in the virtual world of programmes such as Rhino, before being sintered by laser to realise their physical 3-D form (fig 98). This transfer of a technology and its associated materials has resulted in the creation of non-textile textiles, chain mail type constructions used for clothing and accessories in rubber, metal and plastics (Lee 2005, pp.130-140). However, the material output of the rapid prototyping process is limited (although expanding as the technology progresses), narrowing both the performative possibilities of the product and the sensual experience of the user of such products.

The utilisation of rapid prototyping as a tool for manufacture is contrary to the original intention of the technology and revolutionises patterns of production and distribution. Such practice enables localized manufacturing, design files can be sent to rapid prototyping facilities anywhere in the world, thereby minimising transportation of goods and materials. The company need keep no stock and produce items only in response to actual demand, thereby minimising wastage (Kyttänen 2006). However, there are both advantages and limitations to such methods. I am predominantly discussing these drawbacks as they compare to hand crafting techniques.

To make even minor alterations to the form of a hand-crafted object it is often necessary to remake it completely. This lengthens the time taken to complete a design and also increases production costs. Objects constructed in 3-D computer programmes can be quickly altered without destroying previous iterations, amendments can be made and drawings re-drawn with relative ease. However, in some instances the speed often perceived as one of the greatest advantages of CAD could equally be seen as one of its great drawbacks. The time spent re-drawing by hand, although often perceived as onerous, is also time spent idly but actively re-conceptualising a problem (Sennett 2009). On its unplanned journey floating through the subconscious the problem bumps up against all sorts of ideas and knowledge, making connections that are only made if the idea floats around for a considerable time. In the easily adapted world of CAD this thinking time is lost.

Processes that rely wholly on CAD/CAM are in opposition to the intimacy of touch. Although the visual and aural elements of a physical entity can now be adequately reproduced, the tactility and materiality of the mimicked medium is missing. CAD/CAM technologies distance the designer from the designed, removing opportunities for whole body knowing. Generally speaking this virtual medium is a way of working that is clinically separated from bodily experience and all of the tactile knowledge that this interaction brings. Although technologies are rapidly evolving to simulate haptic experience, these are still not fully realised or able to engage our full range of senses in the exploration of an object or an environment. Even if such technologies were further advanced there is no unexpected behaviour of materials in the digital world, virtual materials are uniform and without flaws (Dormer 1997). In ‘real’ making situations the designer interacts with the tools of their trade and the materials out of which the object is made in a three-way conversation. Real materials invariably have flaws that have to be taken into consideration and incorporated into the design. As discussed above, the occurrence of unforeseen problems during the process of hand making can force novel outcomes, whereas in the world of virtual, unflawed materials this opportunity for the evolution of process or form is lost. Additionally, whilst a prepared mind adapts and evolves to accommodate unpredicted outcomes a machine cannot so easily adjust to the unexpected. “Machines break down when they lose control, whereas people make discoveries”. (Sennett 2009, p.113)

Intention, imagination and creativity cannot be replicated by a machine although a machine can be used as a tool to enable these traits to flourish. Those designers who are able to employ both a practical knowledge of materials as well as CAD/ CAM expertise are ideally placed to exploit the exceptional versatility and that potential for novel outcomes that an amalgamation of the two processes could bring. Dormer (1997) describes this happy marriage of digital and tactile knowledge as ‘middle aged wisdom’ as the further we progress into the digital age the more traditional handcraft skills are being lost. Handcraft skills are still very prevalent in the discipline of Textiles and are central to my work. However, these skills have been augmented by the discriminating use of CAD/CAM, modelled on techniques as used in fields such as architecture and product design.

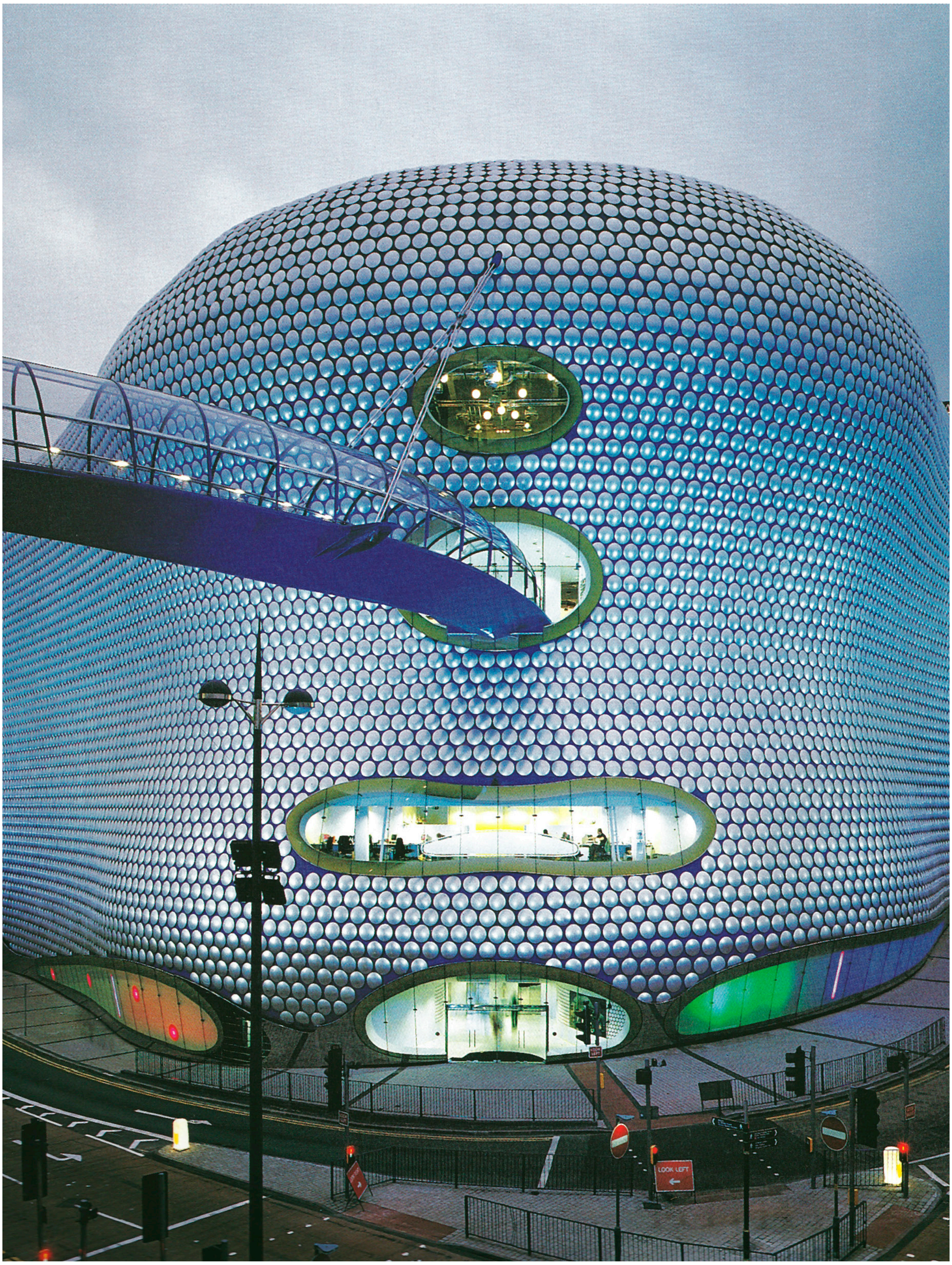


Fig 99. Selfridges Department Store, Birmingham, Future Systems, 1999-2003.

The burgeoning of CAD/CAM technology has lead to a precedent for increasingly complex organic, fluid or 'blob' forms (blob forms being complex free form geometry) in architecture, (fig 99) and product design (fig 100), due to the technology's growing ability to calculate the structural loads and stresses of such complicated forms (Waters 2007). 'Parametricism', a rhizome unfolding from this digital boom, has emerged in the field of architecture as a 'movement', akin to that of Modernism or Constructivism (Schumacher 2009). Architecture, as discussed in chapter 4, has adopted and adapted biological paradigms and models to create organic and emergent outcomes. Utilising CAD 'parametric programming', which simplifies or solves complexity digitally, practitioners of 'Parametricism' can create complex, continuously differentiated forms that mimic biological systems (fig 101). The Tess software I used to develop periodically repeating origami nets (discussed in chapter 4) is an example of parametric programming applied to my project. However, unlike textile practice, where the global duplication of a motif is common, the complex systems of 'Parametricism' avoid the simple repetition of elements, instead striving for the integration or correlation of multiple, non-identical systems, elements and forms. I believe there is much to be gained from exploring the possibilities of such an approach to the development of form in the discipline of Textiles. It could impact dramatically on the types and scales of structures that could be created and the processes by which they are made.

The integration of multiple systems in order to create variable form lies at the core of much textile production and therefore such processes could be naturally suited to the creation of flexible biomimetic structures. For example, when weaving with warp and weft of differing compositions the yarns display differing behaviours that shape the resultant fabric. This variation of warp and weft composition is just one of a plethora of elements that can be varied to affect the outcome. The weave structure, tension or finishing treatment all also have a profound effect on the finished form and can be applied locally to specific areas, or globally to the entire material.

Fig 100. Bloblulous chair, fibreglass with automotive chrome paint and upholstered foam seat, Karim Rashid, 2008.
Fig 101. Nordpark railway stations, Hungerburg station, Innsbruck, Austria, Zaha Hadid Architects, 2004-2009.

There are strong similarities between 'Parametricism' as practiced in Architecture and the complexity and malleability of my physical Textile practice. However, they approach similarly complex outcomes from different directions. Running in parallel folds yet connected by their shared aim and ability to create non-uniform surfaces and structures, they employ two separate approaches that seldom converge. Whilst architecture attains multifarious outcomes through virtual means, using physical models for design development only where they are useful to understand the underlying geometric logic (Schumacher 2009) my textile practice adopts a 'hands on' approach, engaging physically and intuitively with materials, employing digital technologies to enhance this physical practice.

Laminated and laser-cut work

As I increased the scale of my origami folded samples I found that commercially available substrates produced unsatisfactory results. Either they folded easily but were too flexible to be self-supporting at larger scales or they were too stiff to bend well in complex areas of the design.

I began to experiment with commercially available polyester wadding, flattening it in the heat press to create non-woven, non-directional fabrics of various weights; its 100% polyester composition meant folds could be permanently set with heat. These felted substrates were flexible enough to fold but also had enough stiffness to be reasonably self-supporting in larger scale structures. To enhance this self-supporting capability further I incorporated laminated areas to create substrates with variable stiffness.

I wanted the laminated area to be fully fused with the substrate and plastic tiles proved to be a successful solution. Frosted polypropylene sheets of up to 1mm depth were hand cut into small rectangular tiles for

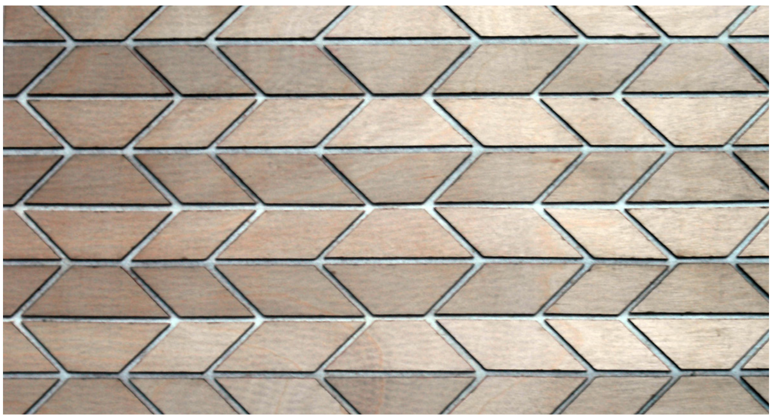


Fig 102. Bonded wood and polyester, sample 58a, 2008.
Fig 103. Felted fused polypropylene and wool, sample 95, 2009.

a number of preliminary material experiments (❖ samples 41,42,45-46,48-51,53). Their low density and light weight added stiffness to the substrate without compromising the performance of the material. I placed the tiles adjacently leaving a gap of 2-4mm. This created a flexible hinge point that delineated the direction of the subsequent fold. These early material experiments suggested that the addition of laminated areas would not only create the local stiffness necessary for the realisation of larger scale folded textile structures but would also remove the need for card moulds for origami folding, allowing much larger piece sizes to be made.

Early lamination experiments included the adhesion of wooden tiles to pressed polyester surfaces using spray adhesive (❖ samples 55-58a: fig 102) and polypropylene bonded to commercially available polyester felt (❖ samples 40, 55-58). Later I explored the potential of these lamination processes to create self-folding systems similar to those developed using textile-printing binders to create contrast of elastic and non-elastic areas on the same surface (discussed in chapter 5). I stretched loosely-knitted wool under tension before laminating polypropylene tiles to the surface (❖ sample 95: fig 103). Washing in a domestic machine at high temperature felted the wool, which pulled the plastic into a similar form to ❖ sample 35. Similarly, in ❖ sample 106 co-polyester tiles were fused onto stretched polyester lycra. However the self-folding behaviour of this material was less pronounced, perhaps in part due to the motifs used but also due to the extended period of time the elastic substrate remained at full stretch before the sample was completed.

The merging of textile and non-textile elements offered the possibility of enhancing useful material properties whilst downplaying less desirable characteristics and behaviours. Through the creation of composite textiles I was able to improve the aesthetic of functionally interesting but unattractive materials. In the first origami-tiled lamination experiments the polypropylene remained visible on one side of the substrate, spoiling the tactile and visual aesthetic of the fabric. Subsequent iterations encapsulated the plastic between two layers of polyester wadding in an attempt to create a unified aesthetic and a more pleasant handle to the textile.

Having achieved an acceptable balance between the performance and the aesthetic of the material I progressed to the development of folded planar form using CAD/CAM technologies to achieve the high level of accuracy required for the realisation of origami folding. I already used Adobe Illustrator to develop positives for exposure of photographic silk-screens and I employed this skill in the development of digital designs for the laser cutter.

My first experience of laser cutting was at a two-day intensive workshop at London Metropolitan University where we were encouraged to interact creatively with the technology. My understanding of the process was significantly enhanced through my full, hands-on engagement with the process, including programming the laser and experimenting with a variety of materials and effects. Although my making was mediated through a digital interface, feedback on material behaviour was immediately available. Burning, melting, clean cuts and scored surfaces could be observed as the laser worked its way across the surface. This playful, process rather than goal-driven engagement with the laser freed my imagination, sparking ideas as to how I could employ this technology in my practice.

I commenced a series of laser-cutting experiments at the RCA, however, unlike my experience at London Metropolitan University I was not programming the laser directly. I was involved while the laser cutting took place and was therefore able to make immediate decisions based on the results of the samples as they appeared, but a technician programmed the laser. As institutional policies changed I, as a student became much more removed from the process. I had to e-mail CAD design files to the technician before dropping off the materials to be cut. These were then cut in my absence at a time convenient to the technician. Institutional policy was imposing a goal-led rather than process-led relationship with the technology. I felt that this created an enforced distance between the design process and the technical manufacture of the materials and meant that spontaneous experimentation was lost from my exploration of laser-cutting technologies in my design practice.

In early experiments I used the laser to score origami crease patterns into both sides of polyester composite industrial filtration felt: mountain folds on one side, valley folds on the reverse. There was some concern that the felt, which contained steel fibre, would not be suitable for laser cutting due to its metal content but this proved not to be a problem. The A4 sized sample (❖ sample 43: fig 104) was correctly registered and although the crease pattern was densely packed, it folded well and retained a full range of movement. I tied the folded form in its packed state before heating at 100°C to set the form. The same crease pattern enlarged to A3 (❖ sample 44) was a better size for the design but the

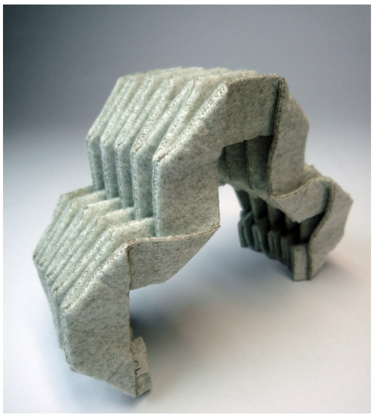


Fig 104. Laser scored filtration felt, sample 43, 2008.
Fig 105. Laser scored filtration felt, sample 43 (bottom) and with slight misalignment in registration, sample 44 (top), 2008.
Fig 106. Immobile ‘Ha ori’ fold sample, fused polypropylene and polyester, sample 47, 2008.

registration of the front and back scoring was out by approximately 2 mm preventing precise folding. After tying and heating the sample had softer, slightly rolled folds, contrasting with the sharp angular folds of the correctly registered sample (fig 105). From these samples it was clear that although laser scoring made the folding of thicker substrates possible, the material was weakened at hinge points where the laser etched into the surface. Holes were created at the convergence of back and front score lines as the laser penetrated the complete depth of the material. A different approach was needed.

I then laser-cut origami crease patterns through polypropylene sheets to make separate tiles that could be laminated onto textile substrates in the manner developed in the material experiments discussed above. Polypropylene is not an ideal plastic for laser cutting as it melts along the incision; the laser also leaves scorch marks. However, it has a melt point of approximately 160°C, allowing tiles to be melted onto the polyester substrate before folds are set at the lower temperature of 100°C. For the first of these samples I used a simple 'ha-ori' fold pattern (discussed in detail in chapter 2), encapsulating the polypropylene tiles between two layers of pre-pressed polyester wadding before heat pressing both sides of the sandwich at 175°C for 30 seconds (❖ sample 47: fig 106). The layers fused exceptionally well, creating a robust material but the tiles had also spread, melting into one another and compromising the mobility of the sample. This was due in part to over heating, the plastic also melted through the polyester layers creating a smooth, shiny texture on the surface of the material, but also an insufficient gap had been left between the tiles. The sample folded to an extent after the application of some force but the resultant structure was rigid and immobile and couldn't be folded into a completely packed state.

As my intention was to create a mobile, transformable structure I remade this sample using a lower temperature and leaving more space between the tiles. This sample folded easily into a packed state



Fig 107. Immobile and mobile 'Ha ori' fold samples, fused polypropylene and polyester, samples 47 & 52, 2008.
Fig 108. Flocked fused polypropylene and polyester, sample 85, 2009.
Fig 109. Foiled fused polypropylene and polyester, sample 98, 2009.

prior to heating setting at 100°C. The hinges moved freely in the finished sample allowing a complete range of movement (fig 107). However, problems arose with the sandwich structure that had not been apparent in the small materials tests. Blisters appeared between one of the polyester layers and the polypropylene. After a series of tests the cause was found to be the use of unpressed wadding in the top layer of the composite. As this layer compressed in the heat pressing process expelled air became trapped between the composite layers, creating bubbling. In future samples I pre-pressed all polyester layers prior to bonding, which improved although didn't totally eliminate the problem.

Unable to stop blistering occurring completely when encapsulating the polypropylene between two layers of polyester I sought alternative solutions to improving the aesthetic of the un-encapsulated plastic. My earlier experiments with flocking in the silk-screen process (discussed in Ch 5) suggested a potential solution. I found that flock paper bonded well with the polypropylene when heat pressed (❖ samples 83–86) imparting a pleasant textile-type texture to the surface that aided the aesthetic integration of the plastic with the textile substrate to which it is bonded (fig 108). This process echoes industrial techniques where automotive dashboards are simultaneously flocked and formed, heated plastic being pressed into pre-flocked moulds, but it creates transformable planar surfaces not rigid 3-D form. In my flocked polypropylene samples slight buckling of the plastic at the heat pressing stage led to differentiated areas of heavily and lightly flocked surface. This was an interesting attribute that emphasised the individuality of each piece.

To expand the range of looks and textures available to me I substituted textile foils in place of the flocking paper. The reflective surface is ambiguous, replicating and disguising the true form of the object and blurring the boundaries of its surface. When a surface is a perfect mirror, it becomes a transitionary surface, revealing that which surrounds it rather than itself (Miller 1998). Using reflective, mirror-like surfaces extends the space to include the viewer. Each viewer becomes part of the piece as they see themselves in the reflection. A series of investigations (❖ samples 87, 93, 94, 97, 98: fig 109) showed that the foil not only bonded completely across the surface of the polypropylene but also in part to the substrate, picking out details of the felted surface texture meaning that lighter-coloured foils created more aesthetically pleasing effects if the sample was to include large un-tiled areas.

The progression to more complex folding patterns highlighted issues of accuracy in the construction process. In my practice CAD/CAM and hand process interweave. Without digital technologies the work would be unbearably laborious. The laser-cutter's constant and easy replication avoids the need for mindless repetition. Designs for the laser-cutter, although drawn out using CAD, were taken from physical paper models. My CAD designs directed the laser to cut along the precise axes of folding, leaving no gap for the hinges but the laser-cutter burnt away only minute amounts of material as it incised these lines. I hand placed the resultant tiles onto the substrate measuring the hinge spaces individually, temporarily glueing each piece in place before bonding the entire design by heat pressing. This system was adequate for the accurate completion of ‘ha-ori’ folding patterns but discrepancies began to arise in designs with more complex rotational symmetries. However, difficulties encountered prompted adaptation, leading to evolution of process and form.

In ❖ sample 54 (fig 110) I used an origami design previously used with paper moulds in ❖ samples 16 & 20 (fig 62). It was very difficult and time consuming to place the tiles accurately as differing gaps had to be left at the hinges to compensate for the complexity of the square folding structure. Despite the improvisational tile placement the sample did fold but unlike its paper moulded counterparts, the form was locked into place. The additional thickness of the laminated substrate when folded so tightly in on itself in such a small-scale design compromised its mobility. This demonstrated the necessity to achieve an optimum balance between the scale of the folded unit and the material thickness.

A larger sample of a different design (❖ sample 82: fig 111) was completed but like sample 54 the pattern had been laser cut without incorporating spaces for hinges, impacting negatively on the accuracy of the hand placed tiles. Also, due to the omission of a crucial cut line in the origami net the finished sample wouldn’t fold in the way I had intended. Forced to allow the form to deviate from its intended structure to accommodate the lesser number of hinges I discovered a folding structure that although sharing many characteristics of the planned design, displayed markedly different behaviour. The original model packed to a straight strip, becoming almost semi-spherical when deployed. The improvised model described a three-sided square when packed, flattening out when opened (fig 112-113). This reiterates lessons learned from the hornbeam leaf of chapter two. Minor variations in orientation or number of folds can have significant impact on the resultant form.



Fig 110. Square fold fused polypropylene and polyester, sample 54, 2008.
Fig 111. Polypropylene and polyester prior to fusing, sample 82, 2009.
Fig 112. Polypropylene and polyester, open sample 82, 2009.

In order to address the design error in ❖ sample 82 I adjusted the origami net for ❖ sample 98 to include both the missing crease lines and very important hinge gaps before re-cutting the tiles. These hinge spaces not only maintained the precision of the design but also enabled me to adhere the entire polypropylene sheet temporarily, weeding out the crucial gaps before heat pressing. This approach changed the painstaking tile-by-tile construction to a more time efficient 'down-in-one' method.

Intending to flock the sample in black I used black polypropylene that would highlight the origami pattern even if a uniform covering of flock were not attained. However, on completion of a preparatory material test (❖ sample 92) it became apparent that the flock adhered substantially to the textile substrate as well as the plastic, resulting in an unattractive finish. I decided to apply foil to the piece instead (fig 114) but my use of black instead of clear polypropylene presented problems.

Even on the small materials tests it was apparent that each colour of polypropylene had a different melt point and spreading behaviour. This larger scale piece exacerbated these differences in material behaviour. In order to achieve the necessary level of bonding I had to use the significantly higher temperature of 200°C and a longer duration of heating. The resultant spread of the black polypropylene meant that the hinges were almost fused meaning that the sample could not be folded properly. Origami folding creates tension in the surface system. The hinge made by the fold is stiff along one axis yet pliable in another; the duality of its role makes it vulnerable to stress. In such folding my aim is to optimise the transformation of form whilst generating the least tension possible. In forcing the hinges to fold, critical stress was created and tears began to open up along some of the creases and so I abandoned the piece, re-making it at a later stage with clear polypropylene (❖ sample 105: fig 115).

Fig 113. Polypropylene and polyester, closed sample 82 tied ready for heat setting, 2009.
Fig 114. Foiled fused polypropylene and polyester, sample 98, 2009.

Fig 115. Foiled fused polypropylene and polyester, sample 105, 2009.

The unintentional inaccuracy arising from the omission of hinge spaces from the earlier laser-cut designs sparked the idea that future samples could purposely incorporate such distortions, exaggerating the displacement of the tiles across the piece. This would give opportunities to relax the rigid grid structures of the designs as appropriate. Space could be opened up in the design to allow different types of folding to occur. Tiles could be interspersed with stitched manipulations or naturally occurring folds, disrupting the machined aesthetic of the laser and providing an opportunity to introduce differentiated form reminiscent of Parametricism.

To explore these ideas further in ❖ samples 85 & 86 I intentionally tiled only part of the substrate, leaving large areas that folded softly in response to the highly directed, sharply folded tiled areas (fig 108). This setting of single or smaller 'hard' folded units into larger surfaces, allowing for surfaces flow between hard and soft folds gives the materiality of the textile its own voice. The re-introduction of semi-controlled and uncontrolled folding into the work presented an opportunity to subvert my preferred controlled ways of working, effectively challenging my practice on both conceptual and physical levels. Using a similar approach a larger substrate (❖ sample 96: fig 116) combined stitched manipulation with origami tiling. This merging of different folding types created a sculptural form in which shape evolved organically as the making progressed rather than being predetermined by an unalterable folding net.

The fusing techniques described above were refined further in the final samples of the project. From ❖ Sample 106 onward I used co-polyester rather than polypropylene tiles to create an almost entirely polyester material that potentially could be more easily recycled. Additionally this plastic had the benefit of giving stiffness apparently equivalent to the polypropylene but using lighter weight sheets. It also spread much less when melted, making accurate calculation of necessary hinge gaps much easier.

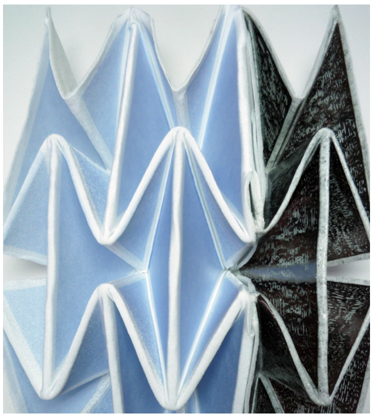




Fig 116. Fused polypropylene and polyester with stitched manipulation, sample 96, 2010.
Fig 117. Front view of samples 117 & 118 joined by clipping along hinge point, 2011.
Fig 118. Back view of samples 117 & 118 joined by clipping along hinge point, 2011.

In order to strengthen the non-woven polyester substrate and to widen the potential range of performance and aesthetic of the self-supporting, structural textiles developed ❖ samples 112-117 & 119-120 utilised hot-melt adhesive to bond knitted and woven polyester textiles to the non-woven polyester and co-polyester laminate. To further broaden the scope of application a simple clipping system was devised, first used to join ❖ samples 117 and 118 (figs 117-118), which enabled the combination of separate modules to create a larger, single unit. This use of notched flaps that fit into precise cuts along hinge points makes it possible to connect a huge range of different folding patterns to create a variable surface that is easily customisable to particular situations.

Touch and emotion in practice

Sensual awareness plays a significant role in my making process. My embodied knowledge of the handle and appearance of the textile is as essential as my technical knowledge of particular behavioural properties in giving a rounded understanding of the textile. However although influential, these different types of knowledge are not consciously conceptualised at the point of making. The process evolves guided by intuition and shaped by my emotional reactions to sensory stimuli.

The physical and emotional sensations generated by touch can be pleasurable or painful. Whist designing I attempt to create surfaces that feel pleasant. In contrast, the making process itself can be extremely physically arduous and painful. Hours spent making repetitive gestures with the hands, stooped over the work takes a physical toll. Surfaces initially appearing soft, over time rub calluses into skin. Tools cut and prick not just the object being made but also fingers. This physical pain impacts on the psyche, influencing the maker's feelings about the object. I, as maker, am hugely emotionally invested in the construction of my work. Emotions fluctuate wildly throughout the process. Stress, satisfaction, frustration, elation, despair and relief follow one another in quick succession as I attempt to replicate the textiles of my imagination.

Commencing the making process my emotional experience is not born from physical sensations given by the object, as it is not yet in existence. The raw materials although perhaps associated with tactile memories have no real emotional significance for me, being as yet un-worked and replaceable. My primary emotional engagement is with an abstract idea of the object. As I proceed my emotion arises primarily from the action and interaction of the activity, sparked by process not materials: an emotion born of verbs not of nouns. As the work progresses my emotional relationship to the work changes, I develop an attachment to the emerging object. Fear of spoiling what is already made blossoms as it nears completion, censoring the hand. Concrete form becomes more significant than abstract idea. I worry about damaging the object, get frustrated when the materials are not behaving as expected or are difficult to fold. Bravery is required to make bold moves at this stage. The activity that started suffused with anticipation becomes marinated in anxiety. The object now has body, history and significance. Particular aspects such as colour or texture stir memories. Materiality rather than process now has the greatest emotional impact.

In my practice there is often a disparity between what I actually make and what I had intended to make once the materiality of the textiles imprint their mark on the process. My development of work is challenged by unexpected events and unforeseen material behaviours, forcing me to adapt my processes and outcomes creatively in order to approximate my minds eye vision of the object. John Dewey says of the artist stumbling across a relevant but unexpected scene,

> “The motor co-ordinations that are ready because of prior experience at once render his perception of the situation more acute and intense and incorporate into it meanings that give it depth, while they also cause what is seen to fall into fitting rhythms.” (Dewey 1934)

Tacit knowledge and technical skill prepare the ground for averting and exploiting potential disaster but it is necessary to go through a crisis of thought and action in order to improve and evolve. Seeming errors can be recast as happy accidents if the body and mind are primed to recognise opportunities for innovation given by deviations from anticipated patterns. I am elated when the sample is finished satisfactorily.

Language cannot fully communicate tactile experience and so meaning is inevitably distorted or lost with attempts to articulate intuitive, embodied making. Touching is ‘a wordless dialogue’ between the human and the material world (Millar 2010). However in academic frameworks this non-verbal interaction must be re-framed verbally. How can this problem of translation be overcome?

A huge advantage of ‘PhD-by-project’ research is that there is the opportunity to engage audiences in tactile exploration of the outcomes of physical practice as the artefacts are available to view and handle. Whilst the researcher must endeavour to construct a verbal explanation of the research process and outcomes these can be further clarified by using different media, for example video and photography to support the writing. In this manner one is able to elucidate different aspects of tactile or embodied experience from a range of perspectives, including those that engage the audience haptically.

This chapter has discussed how touch can generate embodied knowledge that is an invaluable part of the making process. It has considered how this way of knowing can be preserved as part of textile practice while still exploiting the advantages of disembodied digital processes. It has then described how hand and CAD/CAM processes have been combined in the work to create larger-scale, deployable textile structures.

CHAPTER 07

Chapter 7: Folding towards the core

Summary of research approach

The research was structured around three main aims:

Aim 1: To develop an insight into contemporary design, production and application of three-dimensional, adaptable and self-supporting folded structures.

Aim 2: To develop adaptable and self-supporting, three-dimensional structures, as well as production processes and materials for the realisation of these structures as textile forms.

Aim 3: To develop a research methodology that can encompass both the theoretical and practical aspects of the research project.

Each had specific objectives developed to support their achievement (pp 18-19, Chapter 1). Although these aims were met broadly, not all the objectives were fully realised. I comprehensively addressed the first aim through the physical modelling of folded structures, a contextual review that included a literature search, visits to conferences, exhibitions and industrial facilities (see appendix 5), and consultation with specialists from diverse fields. The second aim was addressed by visits to trade fairs and shops to identify suitable materials as well as a series of material and process experiments that led to the development of adaptable, three-dimensional textiles, the most notable findings of which are detailed below in 'Summary of research outcomes'. However, the third aim was only partially achieved. The methodology developed produced incremental innovation in production processes and integrated pragmatic and poetic methods in a way that could have relevance to practice-based research beyond the discipline of textiles, discussed below in 'Summary of research outcomes'. A measure for the success of the study is its uptake by diverse audiences. The dissemination of the research elicited positive responses from people from varied disciplines and these were recorded in the reflective journal and conference notes. However, evaluation of the effectiveness of the research methodology could have been developed further, for example by developing more structured systems for deeper analysis of this feedback.

The fold sustains both physical and conceptual flexibility. It can balance seemingly oppositional states, creating differentiation whilst preserving continuity. Employed in this research as a central focus for the design of textile artefacts it has produced versatile, adaptable structure, transferable to many applications. Used as a structuring principle for the research process the fold has provided a containing framework for the study yet simultaneously fostered a free and flexible approach. Deleuzean interpretations of conceptual folding have promoted creative, analytical and critical enquiry. This approach has eased the integration of potentially conflicting modes of operation e.g. playful yet bounded approaches to the work, verbal and visual ways of thinking, 2-D and 3-D generation of form, as well as the development of design and concept using virtual and physical techniques.

I have employed a 'bricolage' of methods, borrowed from a variety of disciplines to help me maintain this flexibility. These research techniques have predominantly originated from my studio practice, recording and reflecting on this core activity as well as situating it within the wider field of current practice. Methods used have included technical, reflective and creative writing as well as artistic and documentary drawing, photography and video production. These techniques have allowed me to document and ponder the progress of the research pragmatically as well as to engage in imaginative contemplation of future developments. Discussion and consultation with experts from numerous different fields including materials science, engineering, architecture, design and fine art have been central to the research, enabling me to consider the project from various viewpoints and assisting my exploration of the range of possible relationships between the various research materials. For example, the emergent behaviour of textile materials highlighted by architectural modelling processes as well as contemporary textile practice led me to explore their dynamic self-organisational properties in my practice.

'Bricolage' is not a systemised or systematic approach and therefore there can be no quantitative measurement or testing of its success.

> "The researcher's fidelity to procedure cannot simply be checked off and certified. In the complex bricolage the products of research are 'evaluated.'" (Kincheloe 2001, p.689)

As in design, there is no wholly right or wrong answer. The results can be defined only as good or bad, or good enough. However, I feel that by employing such varied methods I have maximised the potential of the research to reveal both intended and unintended technical and artistic results that surface functional outcomes as well as their poetic aspects.

The original aim of my research was to create three-dimensional form on textile substrates through the development of silk-screen printing processes combined with established textile manipulation techniques that focus on folding. However as the project progressed these aims were modified to exploit opportunities presented by the early practical work and my deepening contextual knowledge. I concentrated particularly on the creation of adaptable, transformable form, while the range of production techniques widened to include the adaptation of processes more commonly used in disciplines such as product and vehicle design. The intention was that the three-dimensional aspects of the textiles produced should not be purely decorative in effect but should improve their functionality. This research did not address the development of three-dimensional knit or weave technologies and processes, although textiles produced using these technologies were occasionally incorporated into designs as substrates.

Scrutiny of the effect and application of pleated and folded textiles used for in, on and around body applications highlighted the different, occasionally opposing properties that folding can impart. It also drew attention to more subtle nuances of meaning enfolded in the physical fold, revealing some of its poetic potential. Examination of deployable structures developed for application in areas as diverse as medicine, furniture design, architecture and space exploration gave insight into the wide range of potential application for the textiles developed as well as modelling effective patterns of folding and suggesting possible production techniques. Particular attention was given to the study of biomimetic folded structures and the natural forms that inspired them, increasing my understanding of basic structural principles underlying such forms and how their adjustment could affect behaviour. This understanding was further enhanced by the concurrent construction of origami and shibori models.

Visits to industrial facilities and information gathered at conferences, symposia and trade fairs enabled the analysis and evaluation of established processes for the production of folded structure on textile and non-textile substrates. Studio practice investigated, evaluated and adapted these processes, using techniques including thermoplastic manipulation, silk-screen printing, stitching and bonding to develop three-dimensional folded form on fabrics that possessed self-supporting structural capabilities whilst maintaining a pleasing handle and visual aesthetic.

The embodied knowledge acquired through the physical interactions of studio practice imparted an understanding of both the limitations and the potentials of the materials. This knowledge was employed in the empirical testing of samples produced, building experiential awareness rather than numerical data regarding the constraints of materials and construction processes. Throughout this study materials, processes and forms that didn't conform to flexible set criteria were discarded or adapted in a process of 'natural selection'. For example, origami folding creates tension in the surface system. The hinge made by the fold is stiff along one axis yet pliable in another; the duality of its role makes it vulnerable to stress. It became apparent that non-woven substrates were particularly prone to stress damage at hinge points. Although attempts were made to strengthen these non-woven materials their critical thresholds were not scientifically measured. If these textiles were to be developed further for specific technological applications e.g. aerospace or construction, comprehensive scientific testing would be necessary to ensure predictable and reliable material performance.

Oral, poster and exhibition presentation of my research allowed me to clarify my own thinking, as each event forced an interim summation of the project. Textile pieces were often displayed alongside photographs and videos in order to illustrate the future potentials of my exploratory designs. In such instances the sensual impact of the physical textile artefacts served to ground the as yet unrealised developments visualised in a more tangible reality. Audience interaction played an important role in the adjustment of the functional and fictional narratives of the project, providing opportunities to engage in debate with experts from diverse backgrounds regarding unresolved design issues and potential future developments.

When disseminating the research findings the engagement of different applied disciplines is particularly important, as it is my intention that the impact of this study will reach beyond the discipline of textiles. As the textiles created are not only autonomous physical entities but also speculative design models that can be reproduced in a variety of materials and scales with the potential to adjust functionality as the situation demands they could prove to be a useful design solution in wide ranging areas. I envisage that these textiles will be further developed for specific application through collaboration with specialists in disciplines as diverse as engineering, materials science, architecture, apparel and product design. The foundations for such collaborations have been set by presentation of the work at conferences and other research events on topics including adaptive structures and plastic electronics to audiences that included civil, electronic and aeronautical engineers as well as textile technologists and materials scientists (see appendix 5). The study may also be of interest to practice-based researchers as it contemplates theoretical discussion focusing on the processes of making and provides a methodological model for the integration of multiple methods.

Summary of research outcomes

The folding undertaken as part of this study has transformed my perception of my textile practice as much as it has changed relationships between physical points on the manipulated textiles. Acknowledging the value of the unexpected mobility and transformability of early samples altered the emphasis of my research. As I explored the huge potential for diverse application of these adaptable forms I began to see the textiles created not only as realised pieces but also as illustrations of imagined future outcomes.

These fictional narratives fuelled my imagination, acting as an interface between problem solving and commentary on existing designs that prompted the conceptual development of the project. I came to apprehend that abstract generalisation enabled the development of abstract principles, which widened the scope of the project. This realisation prompted me to stop focusing on prototyping a limited number of specific outcomes for particular applications. Instead I prioritised the development of adaptable process, an approach already recognised in the discipline of architecture. Tessmann notes,

> "The very act of designing is shifting from the generation of objects towards envisioning, implementing and controlling generative processes." (Tessmann 2009, p.52)

Small incremental modifications to established production processes have led to the development of unconventional hybrid textile processes that blur the boundaries between printed and constructed textile approaches as well as extending into other disciplines. These modified processes have been used to restructure textile surfaces.

The rigidification of flexible textile materials is fundamental to the creation of the structural planar forms of this project. This rigidification has been achieved through folding used in isolation as well as in combination with silk-screen printing and fusing non-textile materials to a variety of textile substrates. The differing properties of woven, non-woven and knitted substrates e.g. strength, customizability and elasticity have been investigated and exploited to create self-supporting folded textile structures with varied behaviours and capabilities that need no supporting framework or 'mesh' to attain and maintain their form. The textile membranes developed contain their own integral structural support.

Using current industrial textile pleating techniques but coating natural textiles such as cotton and silk was not particularly successful, having no discernable effect on the permanence of the resultant forms. However building on techniques used in industrial design by fusing plastics such as polypropylene and co-polyester to custom made non-woven polyester substrates I have created non-uniform composite laminates of variable stiffness and with shape-memory capabilities that enable origami type folding of textile substrates without cardboard moulds. Similar effects at smaller scales have been achieved through silk-screen printing. This enables the production of larger piece sizes of origami-folded textiles than currently manufactured industrially. Thickness and stiffness of textiles created using these techniques can be adjusted to create self-supporting structures at wide-ranging scales, avoiding structural collapse when the size of each folded unit is increased.

My experimentation with polypropylene of various colours revealed that each colour had different melt points and spreading behaviours. My later introduction of co-polyester in place of polypropylene moves towards the creation of a more easily recyclable mono-material without impacting negatively on performance. These co-polyester sheets were significantly lighter whilst imparting a comparable amount of rigidity to the substrate and spread minimally when melted. Consideration must be given to these variations when calculating hinge gaps for origami style patterns to enable the form to fold and move as intended. It is also important to balance the weight of the stiffened area in relation to the flexibility of the substrate or gravity will overcome the shape-memory capabilities of the folded form and it will not be self-supporting.

Building on textile and architectural approaches I have developed motifs for the creation of 3D self-folding form on elastic substrates through silk-screen printing. The lamination techniques detailed above have also be applied to elastic substrates, creating self-folding behaviours if applied when the fabric is under tension. This same behaviour can be produced on un-tensioned woollen substrates if felted after lamination. In such instances I have found physical modelling to be an efficient method to establish actual results, as the emergent behaviour of the textile system would be extremely difficult to predict accurately with computer modelling.

Flocking and foiling directly into puff binders and plastics has removed the need for the application of specialist textile adhesives in some processes of production whilst increasing the choice of finish of the textiles produced.

Repeated placement of pattern has been used to generate self-supporting structure, an approach strongly influenced by the development of my research using printed-textile perspectives. I have adapted and reconfigured existing origami patterns to create original designs. The experience gained through this process has reiterated lessons learned from analysis of the hornbeam leaf of chapter two. Minor variations in orientation or number of folds can have significant impact on the resultant form. For example changes to the folding order of identical patterns can mean the difference between locked or mobile structures, equally the addition or removal of a single fold line in a repeated folding pattern can transform a model that packs flat and opens into a curved plane to a structure that does the inverse.

Iterative practice has evolved techniques and forms in a manner reminiscent of biological evolution, generating different and yet related processes and outcomes. The general process and material systems underlying the generation of the folded textile forms of the research were diagrammed through a dynamic process of categorisation. The graphical taxonomy (fig 33, inside back cover) diagrams relationships between the numerous ways of selectively rigidifying flexible textile materials

The flexible taxonomy developed allows for the easy adjustment of parameters in response to the requirements of the situation. Adjustment of the taxonomical relationships between processes and materials by folding together previously unconnected branches of the diagram allows the controlled customisation of the aesthetic and function of outcomes to meet the needs of specific circumstances. The potential for transferable application of the physical outputs of the research has been recognised by people in areas including sportswear, solar harvesting and electronic engineering when the research has been disseminated at conferences and exhibitions. The evolution of these textiles as connectable modular units further increases opportunities for user customisation of the materials.

Lack of time and skill specific collaborative input has meant that a full and proper investigation of non-periodic parametric design has not taken place as part of this PhD research. Similarly, time constraints have meant that I have focused on a small number of the multitudinous possible methods for creating variable stiffness textile surfaces suitable for sustaining adaptable 3D folded form.

Although the textiles, drawings, photographs and videos created as part of this research each have their own autonomy, producing responses from the viewer or user that need no theorisation or explanation, the deeper meanings contained in this multifaceted study cannot be fully inferred unless the work with its various texts, diagrams, artefacts and visualisations is read as a whole.

> "Trying to simplify complex matters gets you nowhere. Eliminating complexity is an attack on the core structure that only leads to damage to the whole. If a complicated matter can be likened to a tangled skein, a complex one is like a tapestry: pulling out threads of warp or woof removes something essential from the patterns and shapes." (Jonsson 2005, p.68)

Unfolding futures

The research undertaken has much potential for further development, both through the adaptation and evolution of the techniques developed throughout the project and through the integration of new technologies.

The database constructed as part of this project extensively documents the development of materials and process, only superficially referencing the folding patterns devised. This emphasis reflects the prime focus of the PhD research on the development of processes for making structural textiles. However, as the research progresses into design for particular applications it would be beneficial to extend the database to include more detailed information regarding the specific behaviours of different patterns of folding. Such systematic documentation of the relationship between form and movement, knowledge that I have developed through practical experimentation, would make it more easily accessible to others. This is important as a precise understanding not only of material performance and production process but also behaviour of form are essential for the efficient development of these textile structures for specific application.

Embedded technologies and digital connectivity are transforming textile practice. Technologies such as wearable computing, sensing technologies, RFID systems and wireless connectivity enable the production of increasingly connected, dynamic and interactive textiles. Integration of such technologies into my folded structures to create self-actuated movement in response to environmental stimuli could enhance their performance, transforming the way users interact with the material and widening the potential applications of these forms.

Existing examples of self-activated material folds can suggest potential direction for such developments. Italian company Corpo Nove has been instrumental in the advancement of the use of ‘smart’ technologies to revolutionise fashion and clothing performance. Although products developed are still conceptual rather than commercial they progress thinking towards future common usage. In 2001 they presented a prototype ‘Oricalco’ shirt, a 5:1 blend of nylon and Shape Memory Alloy (Nitinol). The shirt is self- ironing, reacting to body temperature to regain its original smooth ‘set’ form. It is additionally reactive, rolling up its own sleeves when external temperatures rise (Lee 2005, p.118). A more recent development is the self-folding origami emerging from collaboration between Harvard University and MIT (Urquhart 2010). Combining triangular glass fibre tiles with silicon and shape memory alloy foil hinges, simple aeroplane and boat forms self-fold when activated by an electrical current. There is also scope for the development of less complex mechanical means of self-actuation e.g. the use of hydrogels that are responsive to moisture. With such ‘smart’ surfaces the fold becomes a dynamic point of articulation, instilling life into the planar surface, making it breathe.

Towards closure…and openings

On initial reflection the route this research has traced could be seen as circular. Originating from loosely themed introspective process-led experimentation my project has progressed through several stages. Exposure to a plethora of external influences expanded and enriched the practice immeasurably, suggesting previously undreamt of potentials but also temporarily adjusting the emphasis of my approach from process to outcome. On re-establishing iterative practice as a key approach, designs were created to raise debate regarding the potentiality of folded textile form, production processes and materials for a range of purposes.

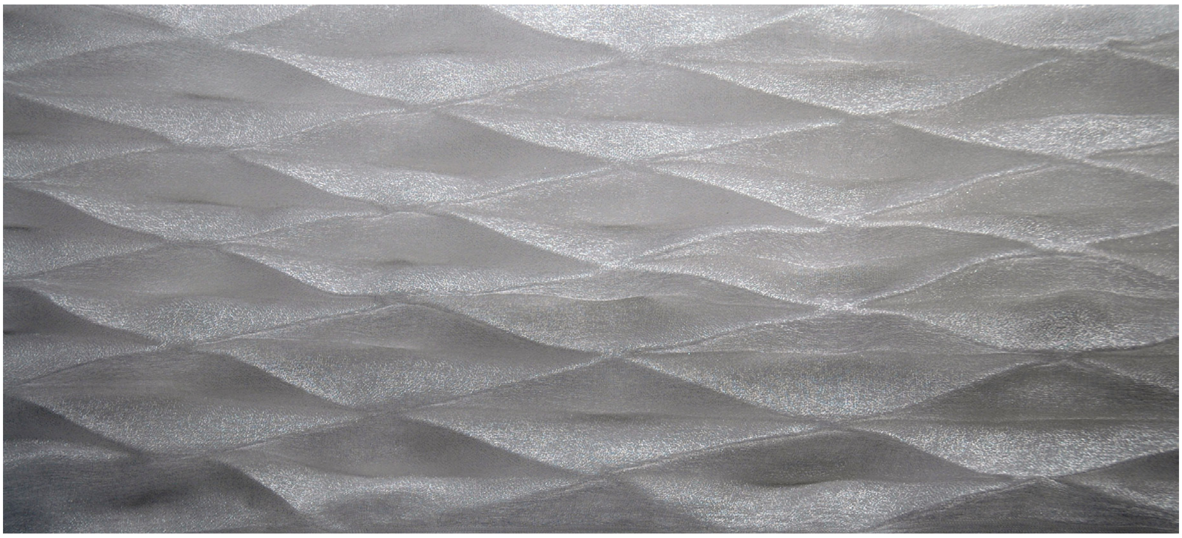
Closer contemplation of my journey reveals its spiralling form, turning in on itself but re-emerging along a slightly different path. Although I may have reprised my original way of working, prioritising process, the passing time has forged different and more complex relationships between these processes, the physical materials and underpinning theories that make up the research. I aim to further evolve this spiral by continuing an active dialogue with research institutes and industry to cultivate future collaborative projects.

> “We shall not cease from exploration
> And the end of all our exploring
> Will be to arrive where we started
> And know the place for the first time.”
>
> (Eliot 1943)

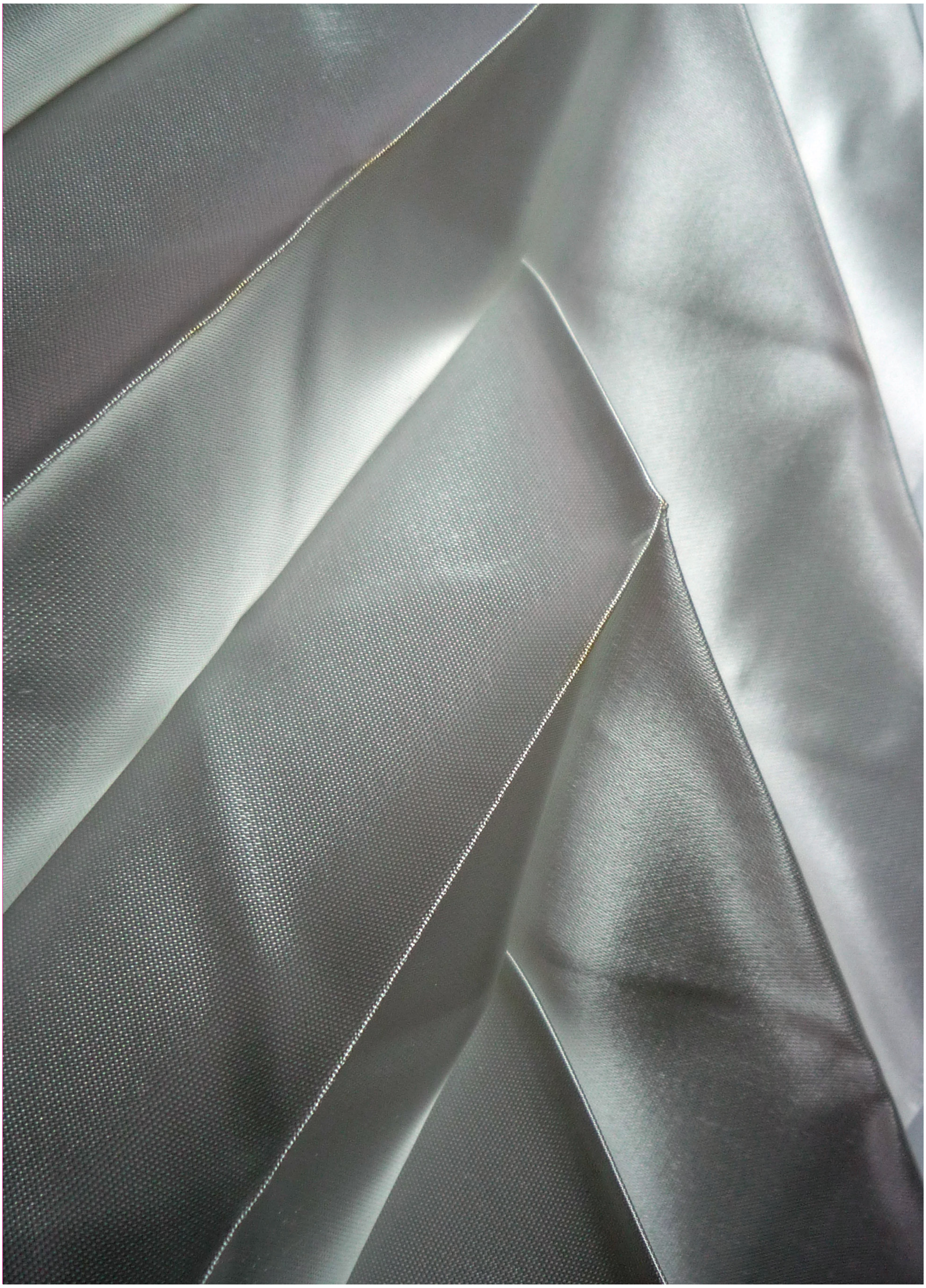
APPENDICES 1-4

Appendix 1

i. Crystal organza origami spiral fold tied in mould.



ii. Crystal organza origami spiral stretched open.
iii. Crystal organza origami spiral relaxed in closed position.



iv. Polyester satin origami moulded knife pleats.

v. Paper mould for knife pleats.

vi. Shibori tied pleats on polyester crepe. (top left)
vii. Shibori stitched forms on polyester satin. (top right)
viii. Shibori tied forms on polyester voile. (bottom)

Appendix 2

Reflections on the making of sample 82 - 31/10/08

These monologues and conversations are edited extracts from transcripts of audio recordings made in tandem with video footage (★ film 1) that document a large part of the making of sample 82 in October 2008.

The majority of the text is my own conversation with myself, reflecting on the making process and thoughts that arose as I made. On one occasion other voices appear. These belong to Michael Park, who assisted with the set up and monitoring of the video equipment and Emma Shercliff, who came into the room at one point in the making. Each person is identified in the text by the insertion of the first letter of their name at the point at which they start speaking.

R = Rachel Philpott **M** = Michael Park **E** = Emma Shercliff

R: It seems like the process of making is having to destroy and remake constantly. So I start with a full sheet of polypropylene and then destroy it. Cut it up into lots of little bits then reconstitute it with this horrible gungy tape to make it back into one sheet. Then I split it all apart again and reunite it in its final position before bonding it irreversibly with other materials in a fusion of textile and non-textile.

In a way although the materials and processes I use aren't necessarily 'textile' when considered in isolation, taken as a whole they are because the piece is constructed in that same painstaking way. Piece by piece, row by row, stitch by stitch you could say: a kind of mutation of knitting and stitching, neither one nor the other. Is it the non-woven or printed equivalent, I wonder?

Making each piece is a completely new learning curve. The whole process is constantly evolving, all the time. It's never quite the same. I think this particular piece of work is as much an exercise in developing methods for recording as it is to develop methods of making samples really. It's a total voyage of discovery.

Emma Shercliff enters room.

M: Hello

R: Hiya. Just push. We haven't got very far. Strangely.

E: I don't want to interrupt.

M: Come in, come in.

E: Wow! It's an exciting film studio.

M: Everywhere. You're on camera actually.

E: Oh! I'd better move out the way.

R: Don't worry.

E: Interruption, that's all part of the process.

R: Yeah. Absolutely. It's so time consuming getting set up and everything. I didn't actually start making before lunch because of the time it took to faff around and get the first bit pressed…. Because I had a thought before I did the first polyester pressing.

E: You had a thought.

R: I had a thought. I had an idea. I had my weekly idea. It chose to come then.

E: At least you have them weekly.

R: And it solved a problem that I'd been having, and it was a real kind of derr moment because you know that, well maybe you don't know that the polyester ones I've made of these before always have a tendency to bubble on one side.

E: Oh right.

R: And I did loads of tests beforehand on Monday, pressing one layer first and then flipping it. Testing if it matters which way up the pressed side is because there's a slight, slight difference between one side of the fabric and the other. So I tried it face up and face down after its been pressed, and tried gluing the polypropylene, which is smooth on one side and rough on the other, face up and face down on the face up and face down. So I did four permutations of that.

E: Yeah.

R: And all still with the unpressed wadding on top. Looking at those this morning and thinking what temperatures I need and how I'm going to do this big piece I finally worked out that it's got nothing to do with that *(laughs)* and that it's pre-pressed wadding or un-pre-pressed wadding, and it bonds better to the pre-pressed wadding. So I need to press both layers.

E: Yes, I guess that prevents any of the airlocks.

R: Yes, I guess so. I guess that's what it is. I did a little test this morning and then came up here. You can see how far I've got. I haven't really glued down very much at all…and I think if I try to have any kind of conversation about it I'm going to lose the plot of where I'm gluing the tiles anyway. I've got too many things to think about so I think it'll just be me and the cameras and trying to work out where I'm going with it, which might be quite interesting

E: Yeah. And you're starting…'cause what I've found was interesting doing a drawing is that when I'm stitching I always start the opposite way round to drawing or writing. You'd usually start top left so that your work is neat but I always start bottom right so I was smudging my drawing as I went up

R: Mmmmm

E: And your kind of starting on the left but you're starting at the bottom not the top.

R: Yes. I think I probably would always start there. Maybe it's a left handed thing because I write from… well everyone writes from that way but it's starting here in the bottom corner and working out. I'm trying to think of the other pieces I've made whether I always do this whitu (*makes whistling noise*). It's like doing the edges of a jigsaw puzzle first, or something.

E: Yes.

R: I always start with that edge, although working with this one it's got more complex. I have learned from the locking one that doesn't open, you know, the square fold, that they become quite complex when you start to put hinge gaps in and I think this is a lesson to me. For the simple fold ones it's easy because there are no twisting folds within folds, if you see what I mean.

E: Is that your double sink fold?

R: Yeah. So the spacing gets very complex and I think actually I'd need to do that on the computer.

E: And prepare yourself with a grid.

R: Yes, next time cut it with the gap so I could just lay the whole thing on, glue the individual tiles down within their grid and then just peel out the grid.

E: Yes, you need a double channel almost.

R: Yes, absolutely. I reckon I could halve or quarter the making time if I sorted some of this out at the design stage, although that's also a making time I suppose. So if I'm going to do a black one, which I think I will, then I'll need to sort out all of these parameters. Making sure that I have a vectorised laser cut file with the hinge gap in there so that I'm ending up with the fold skeleton as well. Maybe I could use the skeleton for something, I don't know what yet. It might be quite interesting to melt that into the stretched fabric and see what happens, I don't know, a mixture of the controlled and uncontrolled fold.
E: Well, I will leave you to get on with it then.
R: I think this film might end up having to be abandoned because I don't get through it, but there you go. I'll have a new piece anyway.
E: It will be interesting to see it anyway. Interesting to view it. I always find there's really interesting choreographies that you find.
Emma Shercliff leaves the room.

R: I wonder if I'm missing a cut there, for the fold. It doesn't look quite right in the centre. I guess it must be, I did it really carefully. It just looks a bit funny now. Often it's getting the first bit set up that's the problem. *(I discovered later in the making process the cut was in fact wrong.)*

How's this going to work with gaps? What I need to get set at the beginning are the gaps on the inner squares, they set the distance for the outer ones. This was the problem with the other square fold sample; it didn't run so fantastically neatly. It's just as well that I've got other things to refer to. So that must go like that. In fact, those are going to have to go that way to fit that in. There we go. Is that really right? It appears so.

In reality everything hinges from the centre here: the centre of the square, not working from the edge, sadly, which would be easier to set up. It has to be slightly further apart. OK, so I might need to take those tiles up and redo them. I'm not as well sorted as I first imagined. So I think those ones need to come out slightly, just ever so slightly, at roughly even rate. There's the thing…the even rate…well that's not it. Looking at this I worry that I haven't made my polyester big enough.

If only this bit were as quick as the pressing, then I'd be laughing. I suppose I learned from my square fold sample so I didn't just blindly align everything to the edge. Hopefully it should more or less tie together. I think ultimately for future samples it makes sense to have these gaps predetermined so that it's all set in the cut and you can just weed out the middle section as waste. In the cut… there's a film reference.

Is it 9.3 that way? I've got the feeling it's miles longer. No, not really, about right. See, that's the trouble while you're making, you don't think about the making you just make. What goes through my head? 9.3, 9.3. Is it square? 9.3. Is it square? Is it 9.3? Roughly. It's kind of square. That's not square at all. Oh dear… That's alright. Right, if I get that right than everything else should follow… Oh, but back ache. Backache follows.

What occurs to me as I make these things beyond that panic that I'm not going to finish in time, and the corrections of the tiles that don't work?

The repetition of numbers, it's quite mathematical. I hadn't really bargained for the mathematical, it doesn't feel mathematical to me. OK. 9.3 as near as damn it, or maybe a tiny bit further apart, I think that'll do. I have 9.3 there, that's OK. Oh, I think I'm going to go off the edge with this. I suppose then I graft. I can graft an extra piece of polyester just slightly askew and it will still be OK. Measure, stick. Measure, stick. I've got to do that at right angles. Here we go, now we have the top angle sorted too.

There's precious little room for the double sink to fold. I seem to recall in the last sample I gave up on the whole measuring thing. I ended up doing a lot of it by eye but when I measured to check afterwards it was nearly always pretty accurate. That's got to go there. There we go. "That's not so bad" she says wincing. Hopefully that's at the right angle. This is virtually impossible. Well, my own fault…I made it. This is valuable lessons learned I suppose. I'm going to have to do a lot more at the computer stage, at the design stage to make it cut right because otherwise it doesn't fit right.

Perhaps I should have done this using black polypropylene; you can't really see what's happening with the translucent tiles. I wonder if you'll be able to see this on the video at all. I'm working with clear plastic and you can just see me on a white piece of fabric making more white pieces of fabric. You can't actually see me doing anything. It's going to be quite funny, filming me, working for ages on something that's completely invisible. I think that's maybe something about the work. A lot of the work that goes into the work is completely invisible. You just wouldn't really think that it would take such a ridiculously long period of time to do.

The thing was, because I did a load of laser cutting at the same time, in a desperate dash towards the end of last term, I didn't get the chance to try out different ways of doing it, if you see what I mean. To work out whether it would be worth…You know, if I'd laser cut one and then made it, laser cut another one and then made it I maybe would have already decided by this stage that it's not worth laser cutting like this, that I should do it slightly differently. I'd have worked out that you really needed to have cut it with the border by now, so I wouldn't be torturing myself like this.

Also I need to get onto the materials library and try to find a laser cuttable material that doesn't burn so, and a polyester at that so that you have mono-material fabric…if its all polyester then it can be recycled as a single shot wonder, which would be much better.

That comes from that so it goes like that. OK. That goes like that and comes like that so goes like that… and again, round like that. Twisty turny, and again round. Each movement the same as you work along the row. Like knitting a particularly awful jumper. I just lay the tiles out one by one and then glue them into place afterwards. If this folds at the end it'll be a miracle. That's what I said with the last one. Hopefully I'm giving enough leeway in the gaps for all of this hopeless inaccuracy.

Maybe I shouldn't worry too much about this because I know there's inaccuracy and I know I could do it better next time but there's always a point in the making when it doesn't go according to plan and then intuition kicks in. Things don't go quite right and you think on your feet. With this piece, because I haven't cut it right I need to improvise, but because I haven't done exactly this before and I just know it's wrong, what I have got? The improvisation is intuitive, perhaps based on previous experience and rationalisation… I've done this similar thing before and therefore that's likely to happen… but actually maybe not in this case because a lot of the stuff I haven't done before, or I've done so little as to be more or less clueless about how it should work. I could almost abandon it now and do it all again but I'm learning so much from doing these big pieces of work. You do those little tests, they tell you about the materials. You do the big tests and they tell you about the form.

I like the white and the purity of white, but at the same time it's a real pain to keep clean. All these little bits get into it from everywhere. And there are some nice black spots embedded in the polypropylene. Maybe in future I need to insist the technician uses some of those tips and tricks I learned at London Met… put paper underneath so it doesn't burn. Where are these dirt specks getting in? Why does it bother me? I should just let it lie, make the piece and see what happens yet because of my nature it has to be as perfect as it possibly can be. Even though aspects of it are going wrong already I still can't just abandon it. The details matter. The details mater desperately to me, so even where it's not perfect and I know it could be better, I still want to do the rest of it as well as I possibly can even though I'm probably going to have to remake the entire thing in what I would now consider to be the right way, although obviously I didn't set out to do it the wrong way.
Now that's interesting. This is a new kind of process so how can there be a wrong way? It just becomes

wrong as I go along, when I realise that it's not working. OK, so let's retrace my steps, maybe it's not the wrong way it's just not the best way. That's probably a better way of talking about it, not the best way it could be done.

Quite exciting to see the piece grow, although it's still going to be days more before its finished. As I say if it folds, miracle time, because everything's just slightly squiffy. Well it might turn out like the locked down one and that's the reason it's locked down. Because I start making slight anomalies in the layout, it means it doesn't move right. It'll still folds after a fashion but won't move right. Right, so I've discovered there are points at which I can ease up these lovely large pieces. I'll use this ruler to try and get some semblance of accuracy back into the work. That would be an interesting point for discussion: the role for accuracy and error in the work. Use this …. (*made inaudible by alarm*)
Oh no! Fire alarm
We're going to have to go.

Right, how did I do those? Badly (*laughs*). Now maybe this is the blurry boundary of the uncontrolled fold because I thought I had it controlled, I was trying to control it but unknown parameters are creeping in where it's not gone quite right, maybe making it not quite as controlled as all that. Not quite as controlled as I would have liked, eh?

OK. Let's sit down. Where are my measuring thingys (*looking for polypropylene block, 3 widths wide*). It's funny how I keep on going back to these although they're probably relatively useless. Ah, see the random potential in there. I guess in this instance, where it starts to go a bit haywire, I measure what I can, try and find pattern and regularity where I can even if its not quite as it should be.

At least by putting the right angles and the measurements back into it at this point I'm hopefully recalibrating it somewhat: mitigating the drift that would have occurred…With all of those mistakes and compromises and intuitive "well I'd better put that there because it won't go anywhere else" moments hopefully this gives a moment of peace, almost a resting place, a check-in.

Now I've actually got stuck into the making I feel quite happy about it… Well maybe it's just while I'm doing these lovely big, fat tiles. It gives an enormous amount of mileage from not so much effort. It's like knitting with chunky wool on big needles. In fact this is almost like a mix of printed and constructed textiles. You've got that painstaking element. The complicated areas where the image builds piece by piece is more like knit or stitch. Then you've got these large flat areas appearing on the fabric, which is maybe more like print.

Oh, right. There's things going wrong here, isn't there? Whoops. So much of this is going to be out of shot. It reflects what Emma talked about; thinking that you're staying quite still and your making area is relatively small when really the range of motion that you go through is really quite large. It's a little microcosm of recursive pattern and this pattern of motion grows into a beautiful physical pattern, a pattern made more beautiful by the fact of what it does, creating its own patterns of motion that adapt and transform structure.

I suppose with the making of a piece it's the setting up of a rhythm that's excruciating, tortuous, um… painful. Mentally it gives me anguish when I'm trying to find my rhythm in the piece, but then I do… although lets see what happens as I'm now back onto complexity. Complexity in simplicity, which has got to end up no matter what 9.3. Whatever happens to the rest of it its got to be square and its got to be 9.3.

I wonder if there is such a thing as a despair of making, I mean the moment when you realise that it's not going to work exactly how you imagined and everything seems futile (*laughs*). But then when you find that rhythm, you realise yes that maybe its not going to be exactly as you imagined but something else will happen instead and that's good too. I feel differently about this than I did earlier on, I really do. I'm just excited to see what will happen. I can't explain why my mood has changed so much through the making of the piece.

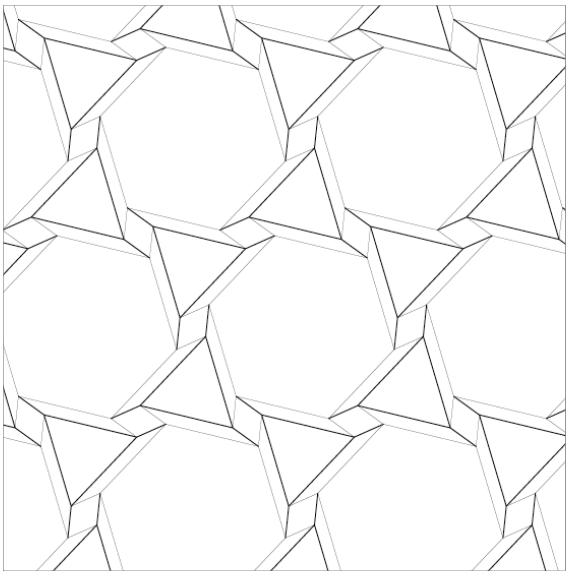
I suppose in this case the pressure of the actual set up of the recording has been a factor, but it's all set now and just chugging away. Maybe part of the stress of making is reaching the point where you can accept that the absolutely perfect isn't going to happen. I never really had myself down as a perfectionist but there seems to be some inherent crunch time sort of thing where you have to decide to let things slide.

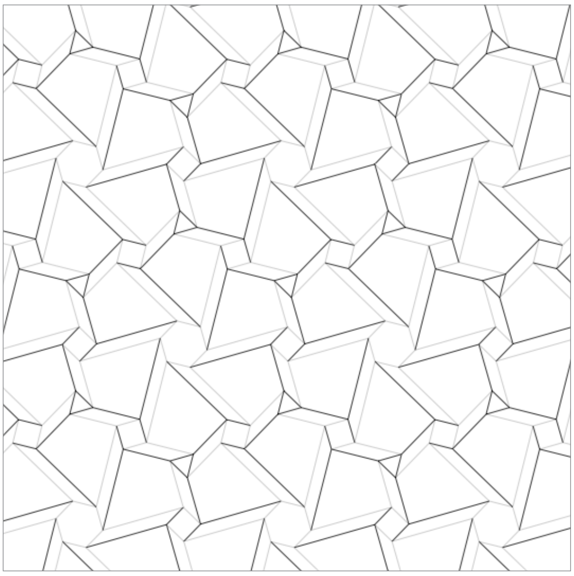
So much of my time while doing this is bound up with getting things right rather than reflecting on what I'm actually doing. Well, I suppose that is what I'm doing…I supposed I'm totally immersed in the process. This here, this little bit just so, this here. Right, so now you should have set up for beautiful… *(Sound of camera beeping)* Yup, yup. OK. Coming, coming, coming. *(Pauses to change video tape).*

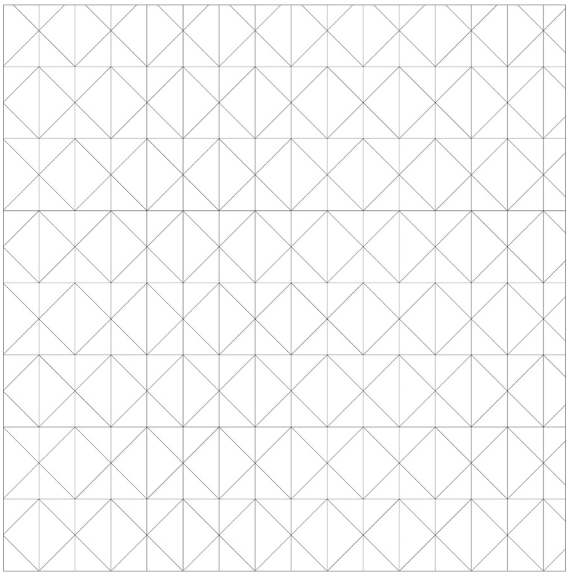
It's Friday night it's Halloween and everyone's having fun, even me. I've wanted to make this piece for ages. And earlier on I was really taken up with the stress of it all and the worry about it, would it work, will it not. But the fact is that now I'm just enjoying the making. Seeing it grow, it's beautiful…in so many ways. It makes me happy to create beautiful things and I really hope it works but it will be worth it whatever happens. And it's so worthwhile this week to have done some making; it's good for the soul, however much writing I've got to do. This really pushes things forward so much quicker than the writing. I might moan about how long this has taken, progressing in geological time like movement on a big glacier, so slowly, but think about how time-consuming the writing process is and how I creep forward with my concepts. Inch forward, wriggling, struggling. I find this hard but the writing's so much harder.

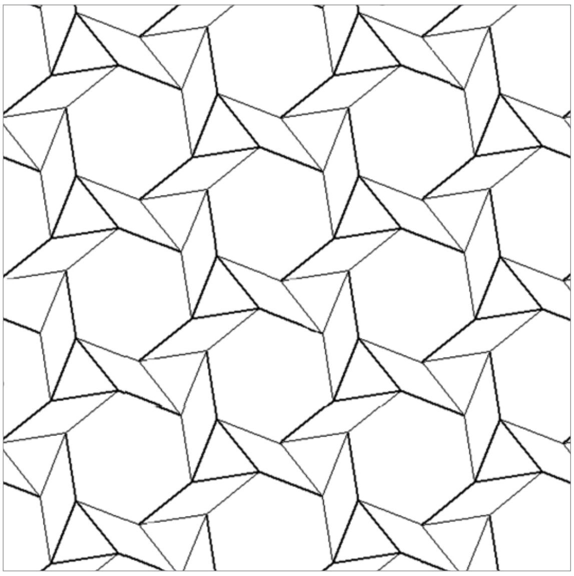
Look at that sample emerging, how exciting. It's simplicity and complexity all at once, conflicting and oppositional. Research in general seems to be conflicting and oppositional. The trick is to figure out how to tease things into enough order to work together as a whole.

Appendix 3

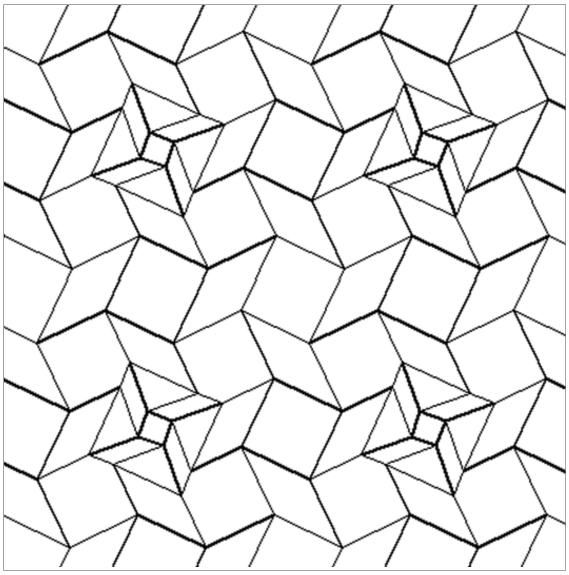


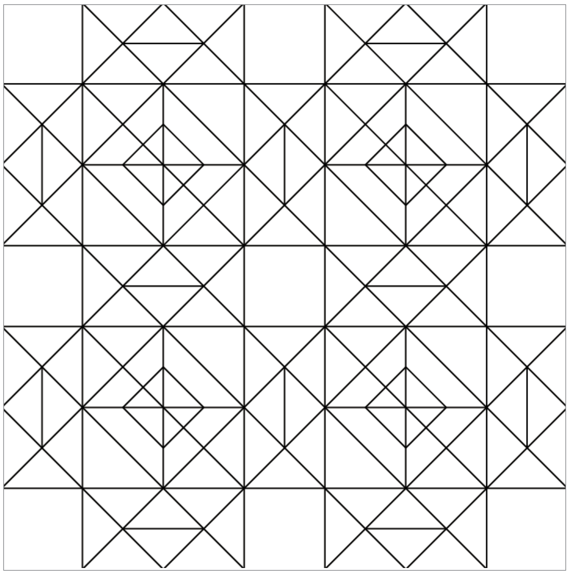




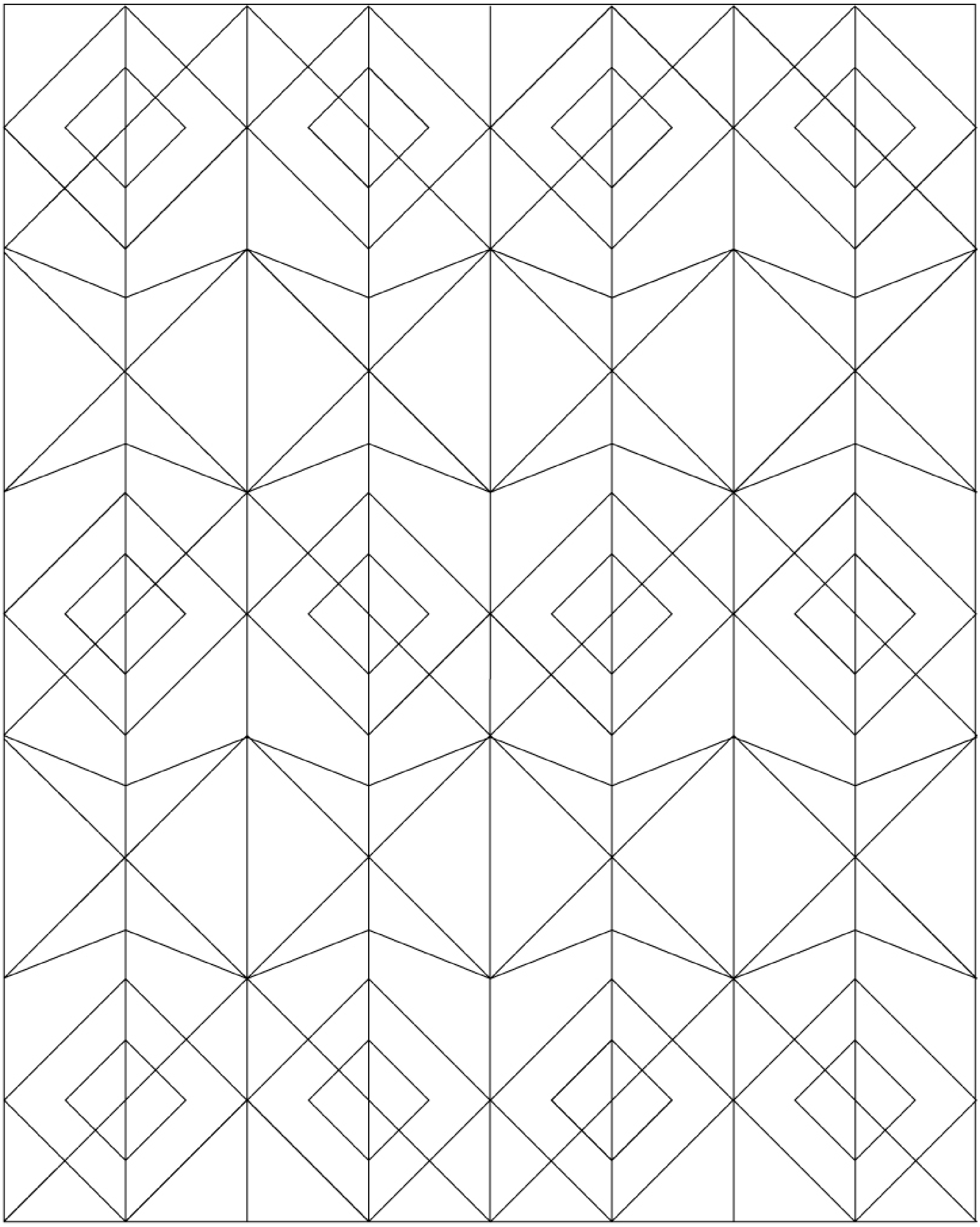


ix. Hexagon fold origami net by Alex Bateman, used for sample 14. (top left)
x. Rotating hexagon fold origami net by Alex Bateman, used for sample 15. (top right)
xi. Magic ball origami net by Kade Chan, used for samples 116-120. (bottom left)
xii. Author’s amended hexagon fold origami net, used for sample 17, 19, 25 & 30. (bottom right)

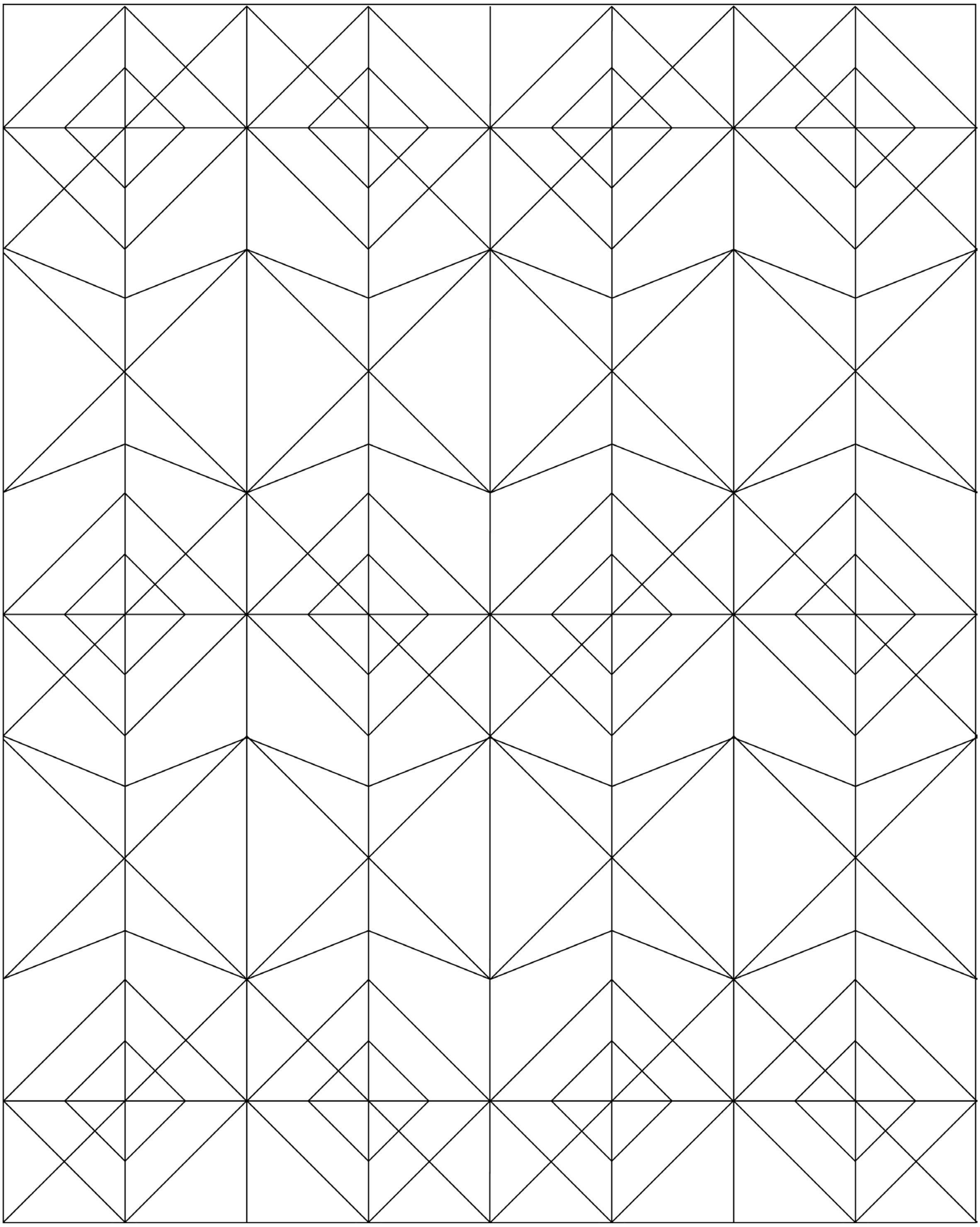




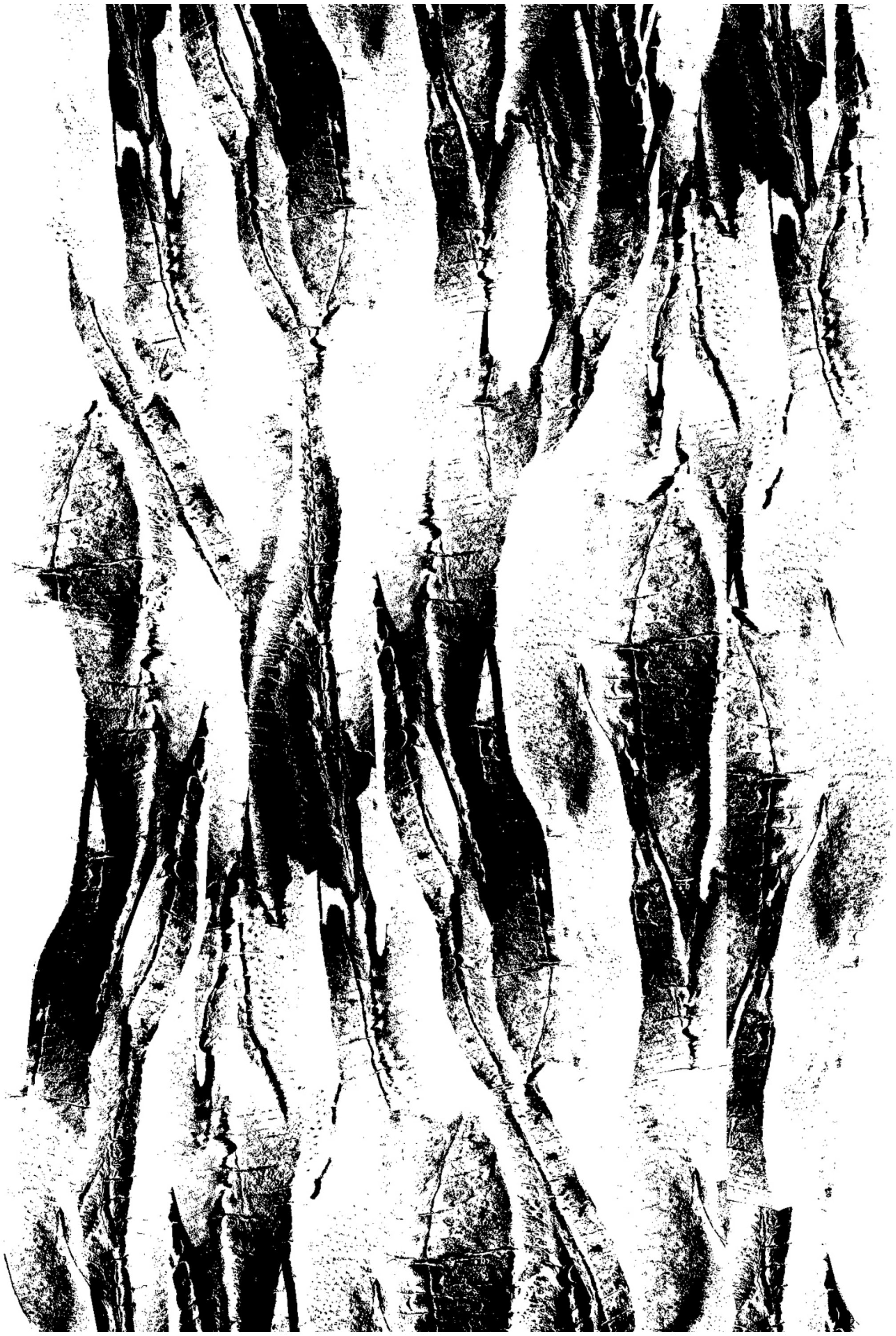
xiii. Author's square fold origami net, used for samples 16, 20 & 54. (top left)
xiv. Author's simple fold origami net, used for samples 43, 44, 47, 52, 58a & 96. (bottom)
xv. Author's unpackable double sink fold origami net, used for samples 36-39. (top right)



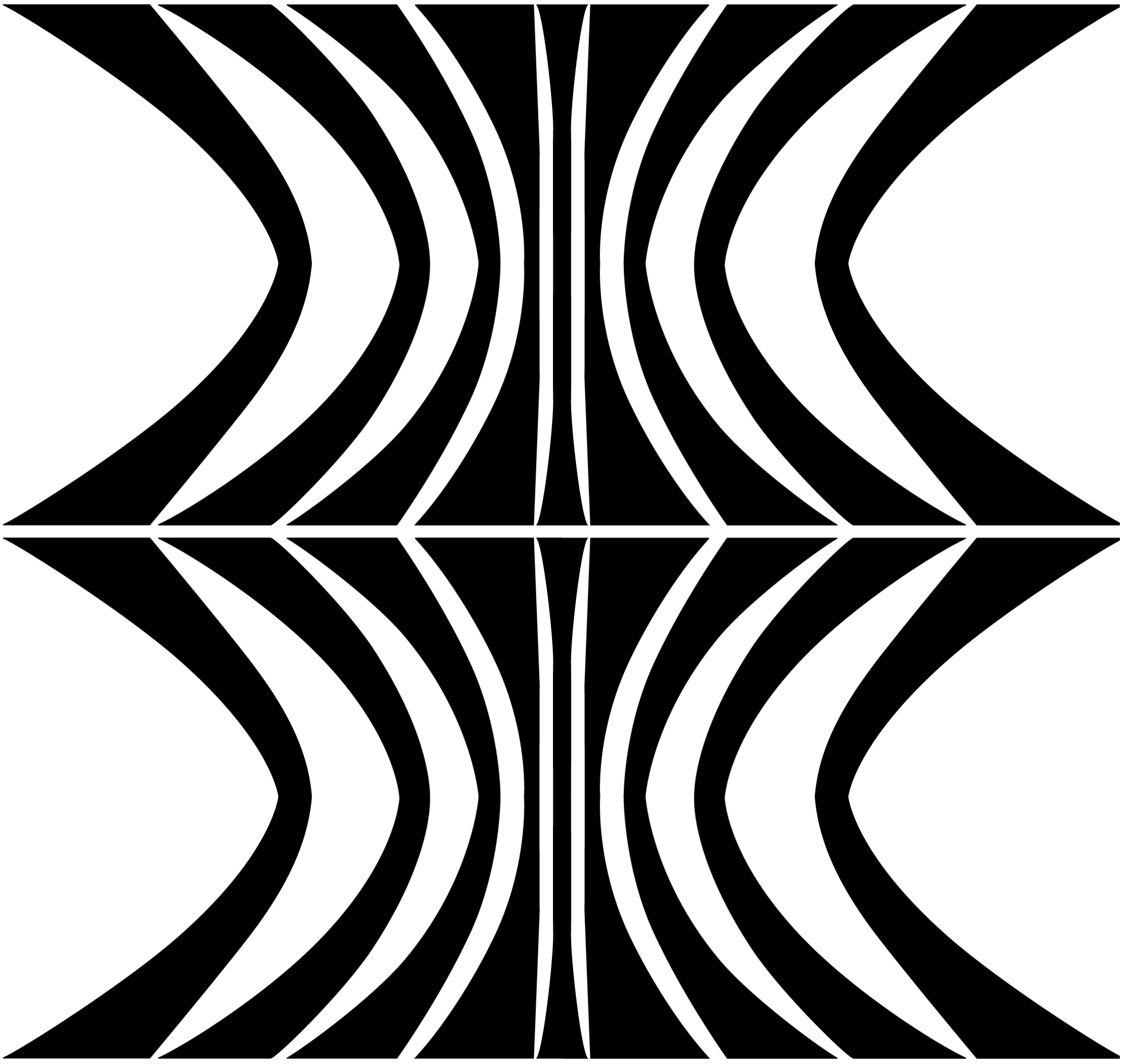
xvi. Author’s packable double sink fold origami net, designed through improvisation after error while making sample 82.



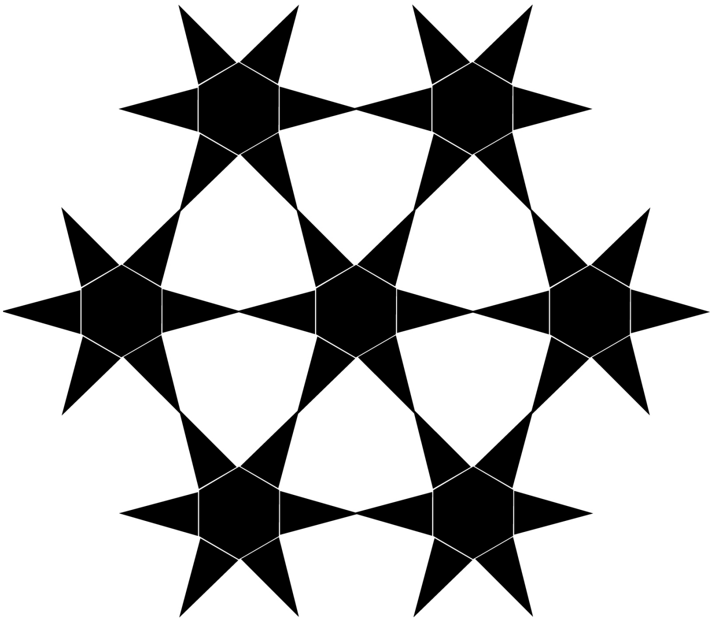
xvii. Author's packable double sink fold origami net, corrected design used for samples 98 &105.

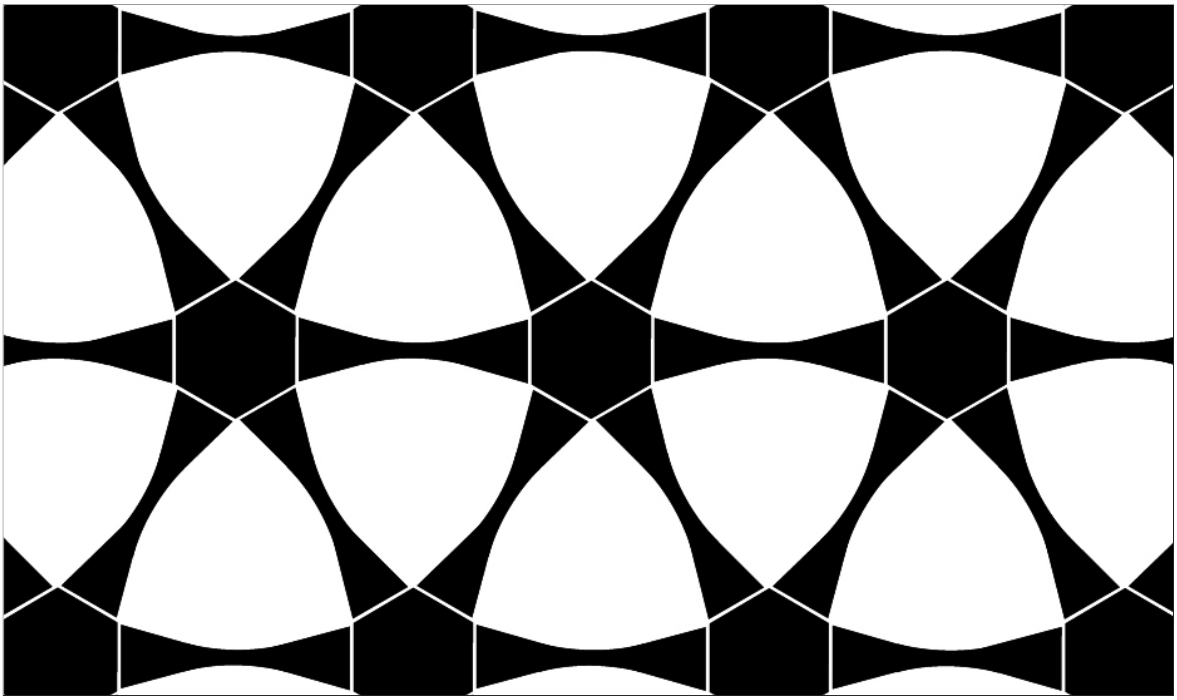


xviii. Author’s bark motif, used for samples 4-12, 18.



xix. Author's ribs motif, used for samples 22 & 28.





xx. Author's star motif, used for samples 23, 24 & 27. (top)
xxi. Author's amended star motif, used for samples 29, 31-35 & 95. (bottom)

Appendix 4

Ways of knowing and making: searching for an optimal integration of hand and machine in the textile design process

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Abstract

Textile design methodologies are evolving to embrace opportunities for innovation given by technological developments in both process and materials. Transfer of CAD/CAM technologies from disciplines such as architecture and engineering is contributing to the dissolution of boundaries between textile and non-textile, leading to the design of exciting new products. In this changing landscape the textile designer becomes more than creator of functional, commercial products; the application of art & design perspectives and methods to technological development can expand the discourse beyond purely functional parameters, suggesting alternative futures where beauty, utility and intuition all play a role.

Our knowledge of textiles is largely mediated by touch. Much textile design practice is still carried out intuitively, informed by tacit knowledge gained through tactile, sensual exploration of materials. This paper investigates ways in which the benefits of CAD/CAM technologies can be realised whilst retaining playful, intuitive exploration that can humanize disembodied digital processes and outcomes.

A case study illustrates how hand and machine processes were interwoven to create textiles with inherent structural properties. Aesthetic, yet not purely decorative, predetermined folds transform 2-D surface into 3-D form, creating adaptable structures with potential application across various disciplines in wide-ranging scales and materials.

Key Words

CAD/CAM, technology, hand making, embodied knowledge, innovation.

Introduction

Textile design methodologies are evolving to embrace opportunities for innovation given by technological developments in both process and materials. Where many textile design processes used to be carried out by hand, now ‘artists and artisans are … embracing two opposites – hand and technology.’ (Wada, 2002, p.145) Traditional textile techniques employ the whole body in the processes of production. Our tactile, proprioceptive and kinaesthetic senses are equally as important as vision and intellect in enabling the creation of novel textiles when using such methods. The progression of the textile design and making process towards increased exploitation of digital technologies presents the challenge of adjusting empirical craft processes to incorporate design engineering.

Since the industrial revolution machine making has to a large extent removed embodied knowledge from the process of manufacture and more recently CAD/CAM has extended this disembodiment to the process of design. This carries the danger that the distance created by such ‘virtual’ methods could lead to a detrimental separation of hand and head where ‘both understanding and expression are impaired’ (Sennett, 2009, p.20). Whilst vision, prioritised over the other senses in the CAD/CAM process, gives a detailed description of the surface features of our environment, it is a superficial mapping of the landscape. Touch provides insight as to how these elements are interrelated. ‘Whereas topography is visual, ‘topology is tactile’’ (Connor, 2004, p.323). This paper investigates possible ways to reap the benefits of CAD/CAM technologies without losing important opportunities for understanding and innovation presented by embodied knowledge of hand making.

Exclusively CAD/CAM approaches

CAD/CAM technologies such as laser cutting and laser-sintering enable the production of complex structures directly from 3-D computer modelled or scanned designs in ways impossible even just a decade ago. Designers are altering their approaches to integrate of these technologies into their practice. In disciplines such as architecture and product design this has lead to a precedent for increasingly intricate organic, fluid or 'blob' forms using complex free form geometry due to the technology's growing ability to calculate the structural loads and stresses of such complicated forms as well as to manufacture them in a range of materials (Waters, 2007). Production methods predominantly designed for use in engineering disciplines are drifting into other areas, contributing to the dissolution of boundaries between textile and non-textile and leading to the design of exciting new products as disciplinary boundaries blur.

The Dutch based company Freedom of Creation, headed by Kyttänen has exploited the potential of rapid-prototyping technology to integrate design and manufacture into a single, streamlined process in which hand-crafting and embodied knowledge are completely absent. The disembodiment of these digitized designs is arguably reflected by their 'other-worldly' synthetic aesthetic, constructed as they are in the virtual world of programmes such as Rhino, before being sintered by laser to realise their physical 3-D form. This transfer of technology and its associated materials has resulted in the creation of non-textile textiles, chain-mail type constructions used for clothing and accessories in rubber, metal and plastics (Lee, 2005, pp.130-140).

There are both advantages and limitations to such methods. Although the utilisation of rapid prototyping as a tool for manufacture revolutionises patterns of production and distribution, enabling localized and on-demand manufacturing that minimises transportation and storage of goods and materials, the material output of the rapid prototyping process is currently limited, narrowing both the performative possibilities of the product and the sensual experience of the users of such items.

Another challenge facing processes that rely wholly on CAD/CAM is their removal of the intimacy of touch from the design process. I suggest that our intimate and ubiquitous daily bodily contact with textiles fosters an extremely close relationship between textile designers and the materiality of their discipline. 'Because clothes make direct contact with the body, and domestic furnishings define the personal spaces inhabited by the body, the material which forms a large part of the stuff from which they are made – cloth – is proposed as one of the most intimate of thing-types that materialises the connection between the body and the outer world.' (Attfield, 2000, p.124) Our experience of textiles is sensory, felt and lived as much as conceptualised.

Much textile design practice is still carried out intuitively, using hand-making processes informed by tacit knowledge gained through tactile, sensual exploration of materials. Our senses co-operate to construct a complete physical and emotional conception of an object from the feelings that are generated in the body. 'The interaction of various sensory media creates a multiple layering of meanings that 'all add up to one message'' (Kondo, 2004, p.207). The understanding given by this synthesis of the senses is far more complex than could be imparted by any single sense working in isolation. A vocabulary of touch builds up over our lifetime and is a cultural phenomenon learned along with language (Classen 2005). This whole body knowing, unarticulated and un-conceptualised is tacit knowledge, carried unconsciously within one but informing the activity of making.

Figure 1: Hand pleating textiles at F. Ciment (Pleating) Ltd

The hand is the most highly developed pre-lingual part of the body (Tallis, 2003), acquiring sensual sensory knowledge through the manipulation of materials. Driscoll (2009) identifies two distinct ways the hand touches. Manipulative, functional touch, for example folding a towel or doing up a button, is a sub-conscious action that employs tacit knowledge while sensual touch consciously seeks out the feeling of the surfaces contacted, noting the pleasure or pain that such contact brings. Both types of touch combine in the making process, facilitating deeper understanding of technical limitations of processes and physical properties of materials. Sennett describes this as ‘material consciousness’ (2009, p.123). New sensual knowledge acquired throughout the making activity can over time become assimilated into one’s sensual vocabulary as tacit knowledge or practical wisdom.

Embodied tactile knowledge of material properties influence the forms created, the maker’s physical interaction with the materials leading to a metamorphosis of material through process. Hand making can be a repetitive process but slight variances of movement, pressure or temperature affect outcomes. No two hand made objects are exactly alike. In the making process the hand becomes intellectual, enabling the simultaneous creation and analysis of work. Observation of my own practice shows my hands constantly, unconsciously adjusting and appraising the work.

It is not only the sensory information generated by the making process that is so important to retain. The speed of execution, often perceived as one of the greatest advantages of CAD could equally be seen as one of its great drawbacks; it creates temporal distortion. To make even minor alterations to the form of a hand crafted object it is often necessary to completely remake it. This lengthens the time taken to complete a design and also increases production costs. Objects constructed in 3-D computer programmes can be quickly altered without destroying previous iterations, amendments can be made and drawings redrawn with relative ease. However, the time spent redrawing or remaking by hand, although often perceived as onerous, is also time spent unconsciously but actively re-conceptualising a problem (Sennett 2009). On its unplanned journey floating through the subconscious the problem bumps up against all sorts of ideas and knowledge, making connections that can only be made if the idea floats around for a considerable time. In the easily adapted world of CAD this time for absent-minded reflection is lost.

CAD/CAM technologies distance the designer from the designed, removing opportunities for whole body knowing. Generally speaking this virtual medium is a way of working that is clinically separated from bodily experience and all of the tactile knowledge that this interaction brings. While the visual and aural elements of a physical entity can now be adequately reproduced in many CAD programmes, the tactility and materiality of the mimicked medium is missing. Even if emerging tactile simulation technologies were further advanced, as Dormer (1997) points out, there is no unexpected behaviour of materials in the digital world, virtual materials are uniform and without flaws.

In ‘real’ making situations designers interact with the tools of their trade and the materials out of which the object is made in a three-way conversation. Real materials invariably have flaws that have to be taken into consideration and incorporated into the design. The occurrence of unforeseen problems during the process of hand making can force novel outcomes; in the world of virtual, unflawed materials this opportunity for the evolution of process or form is lost. Additionally, whilst a prepared mind adapts and evolves to accommodate unpredicted outcomes a machine cannot so easily adjust to the unexpected. ‘Machines break down when they lose control, whereas people make discoveries.’ (Sennett, 2009, p.112)

Integrated approaches

Intention, imagination and creativity cannot be replicated by a machine although a machine can be used as a tool to enable these traits to flourish. Those designers who are able to employ both a practical knowledge of materials as well as CAD/ CAM expertise are ideally placed to exploit the exceptional versatility and that potential for novel outcomes that an amalgamation of the two processes could bring. Heatherwick Studios provide a methodological model for such integration, moving fluidly between CAD/CAM and numerous other means of design ideas generation and production. As he moves between product design, civil engineering and architecture Heatherwick migrates his methods, re-imagining design and manufacture in an innovative way that creates what Sennet would describe as a ‘domain shift’ (2009, p.127). His process moves from hand drawn visualisations and physical modelling to digital modelling and making, followed by hand finishing. His use of a giant crane mounted CNC router to lathe out a smooth circular building from layers of pre-constructed concrete blocks is a visionary transfer of technology and provides an excellent illustration of the integration of digital technologies with craft practice to create innovation. Serres writes of the unification of body and tool in practiced use, the hand becoming the hammer it holds. (Connor 2004, p.321) Heatherwick adapts digital technologies to function as a natural extension of his embodied practice. Dormer (1997) describes this happy marriage of digital and tactile knowledge as 'middle aged wisdom', due to the fact that the further we progress into the digital age the more traditional handcraft skills are being lost.

Case study

My own practice interweaves hand and machine processes to create textiles with inherent structural properties. Aesthetic, yet not purely decorative, predetermined folds transform 2-D planar surface into 3-D form, creating adaptable, deployable structures with potential application across various disciplines in wide-ranging scales and materials. Handcraft skills still very prevalent in the discipline of textiles are central to my work. However, these skills have been augmented by the discriminating use of CAD/CAM, modelled on techniques used in fields such as fine art, product design and architecture.

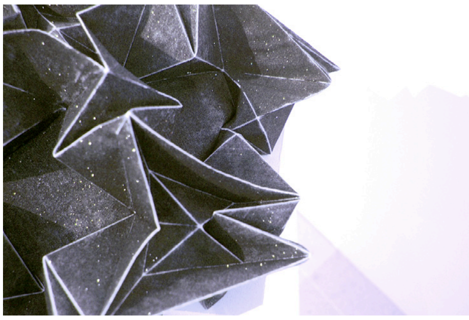

Figure 2: Deployable textile with predetermined printed folds.

CAD for development of concept

As I develop speculative designs the use of visualisation using techniques such as hand drawn and computer-generated image, film and animation has been important for concept evolution and communication. Video is for me a key method for the dissemination of my work. Initial films were made primarily to show my samples in motion, mobility being a key component of the work difficult to demonstrate within the constraints of the gallery or lecture hall. However each subsequent iteration of the film progressed further into abstraction, assisted by my expanding knowledge of filming and editing processes.

Using Final Cut Pro software various filters and effects were applied in an attempt to abstract the object to a degree that moved the image beyond the actual and into the realm of the conceptual. A very tight focus was used as a deliberate device to make scale ambiguous, freeing the imagination to perceive the object from new perspectives. The use of physical mirrors and the mirror facility within Final Cut allowed me to explore 'fictional' folds that could never exist in reality. By layering images I was able to illustrate graphically the potential of combined hard and soft folding although such pieces had yet to be physically completed. Although this overlaying of images was originally undertaken purely as an artistic device it suggested future development of work as dual layer structures. Such developments could increase possibilities for multi-functionality, like two-faced fabrics that demonstrate complimentary properties.

Figure 3: Video still with layered images contrasting hard and soft folds.

The inherent contradiction of using video, essentially coloured light, to depict tactile textile surface was turned to my advantage. Using video I was able to give very rough and ready models the appearance of resolution, shooting both paper and fabric models without there being an obvious difference between them. Obscuring the tactile transformed my relationship to the textile, creating alternative frames of reference that unleashed imagination. The videos now not only captured the dynamism of the folded structures but also intentionally abstracted their physical form to encourage a re-conceptualisation of the object, its scale, its shape, its material. This moulded the next iteration of the physical form in a cyclical process, the re-design of physical space occurring through oscillation between physicality and immateriality, a journey from 3-D textile to 2-D screen and back again.

Integrated CAD/CAM and hand-making techniques

The balance between hand and CAD/CAM processes constantly shifts as the work progresses. Initial samples were created using predominantly hand techniques, employing CAD only to create silk-screen positives by adapting drawings and photographs in Photoshop or creating geometric tessellations in Illustrator.

As my inquiry began to focus on origami structures I had to develop original folding patterns in order to control of the function and aesthetic of the textiles created. At the start of this process the use of CAD gave me an entry point into this complicated activity. ‘Tess’, a tessellation-generation programme developed by Alex Bateman specifically for the purpose of generating origami nets enabled the creation of designs of great complexity and allowed the effect of folding to be seen in advance. However, while the use of CAD software allowed the relatively easy generation of folding patterns, when using these computer-generated nets I found I didn’t fully comprehend the connection between the flat diagram and the resultant form.

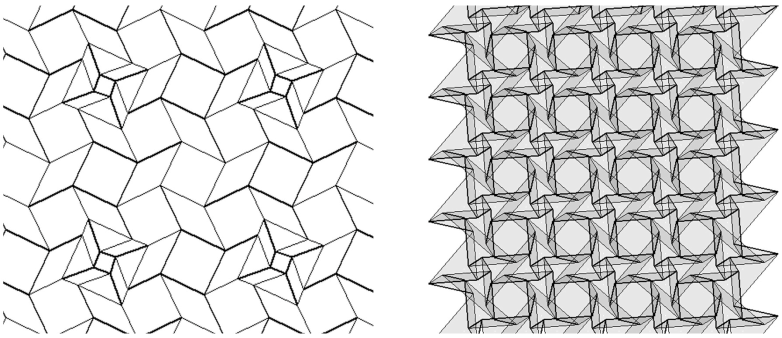

Figure 4: Origami net and fold pattern designed using 'Tess' software.

Joseph Lim notes, ‘When the representational means becomes the media in which the design process operates, then the construction/ material system is constrained by the representational means’ (2009, p.9). Focusing on the generation in virtual worlds of two-dimensional, linear maps of three-dimensional forms severely limited my control of the material 3-D outcomes. Although I was able to adjust origami designs quickly using the ‘Tess’ software I was not developing any underpinning theoretical understanding of the process.

While CAD/CAM and textile design share a common mathematical foundation, in textile design mathematical principles such as proportion, symmetry and tessellation are applied almost instinctively to real, physical situations. In a process typical of many designer/ makers, I often explore the development of my textile forms physically, intuitively employing my understanding of the relationship between materials, process and form to create complex geometries without fully comprehending the abstract mathematical principles that govern them. For me, as for many designers and crafts people, skill in making is attained through the integration of tacit, embodied knowledge with intellectually rationalised technical understanding, overlaid with imagination. Whilst consciously considered technical knowledge informs the preparation of the task, at the moment of making touch guides my actions allowing me to work intuitively to the strengths of the inherent qualities of the material. This could be described as ‘the intuition of the un-thought known’ (Bollas, 1987). To be guided by touch is to put conscious action aside in favour of intuition and emotion. Using CAD to create the origami designs allowed no opportunity for such embodied understanding, leaving me unable to predict how adjustment of the diagram would affect the resultant form. I found that without this understanding I was unable to adapt the CAD designs in any systematic way.

To overcome this hurdle I began working through my ideas directly on paper, thereby incorporating the material 3-D form into the design process from the outset, meaning I could experiment more intuitively with structure and pattern. By learning how to adjust and customise traditional origami bases through physical experimentation I developed an understanding of the relationship between crease pattern and folded form. The ability to employ a variety of folding techniques and to identify the potential behaviours of such folds fostered a more fluid way of working. Structures could evolve iteratively, moving between physical and virtual worlds as tacit knowledge developed through physical folding could then be applied in virtual contexts. Origami nets could now be documented from the models as well as be computer generated to dictate outcomes in advance.

Moving from the design to production of my folded textiles and inspired by the non-textile textiles of Freedom of Creation I exploited the potential of merging of textile and non-textile elements in composite textiles. Laminating specific areas to create substrates with variable stiffness offered the possibility to enhance useful material properties and behaviours whilst down playing less desirable characteristics. I hand-made numerous samples to achieve an acceptable balance between the performance and the aesthetic of the material developed but the progression to more complex folding patterns highlighted issues of accuracy in the construction process. I already used Adobe Illustrator to develop positives for exposure of photographic silk-screens and I employed this skill in the development of digital designs for the laser cutter. Production of tiles for lamination using CAD/CAM technologies achieved the high level of accuracy required for the realisation of origami folding. The laser-cutter's constant and easy replication also avoided the need for time consuming, mindless repetition.

My first experience of laser cutting was at a two-day intensive workshop where we were encouraged to interact creatively with the technology. My understanding of the process was significantly enhanced through my full engagement with the process, programming the laser, watching as it cut and engraved, and experimenting with a variety of materials and effects. The effect of synaesthesia and other less extreme overlaps between the senses can facilitate a whole body knowing of the material even when no physical contact occurs. This crossover of senses allows one to feel an object without touching it. Memory aroused by visual stimulus awakens haptic consciousness, as Pallasmaa says 'Vision reveals what touch already knows.' (2007, p.42) Although my making was mediated through a digital interface, feedback on material behaviour was immediately available. Burning, melting, clean cuts and scored surfaces could be observed as the laser worked its way across the surface. This playful, process rather than goal driven engagement with the laser freed my imagination, sparking ideas as to how I could employ this technology in my practice.

Figure 5: Origami folded textile with laser cut, laminated areas.

I commenced a series of laser cutting experiments at a different workshop but unlike my previous experience, I was not programming the laser directly. A technician did that task although I was still very much involved while the laser cutting took place and was therefore still able to make on-the-hoof decisions based on the results of the samples as they appeared. However, as institutional procedures changed I became much more removed from the process. I had to e-mail CAD design files to the technician before dropping off the materials to be cut. These were then cut in my absence. Institutional policy was imposing a goal-led rather than process-led relationship with the technology that limited opportunities for fully exploring its potentials. I felt that the enforced distance created between my design and the technician manufacture of the materials meant that spontaneous experimentation was lost from my exploration of laser cutting technologies in my design practice.

Conclusion

CAD provides a significant opportunity for alternative methods of conceptual development, progressing practice by revealing possibilities not limited by physical constraints. CAD/CAM allows for greater design complexity at the same time as improving accuracy and reducing production times. This makes the resultant products more cost effective and therefore more commercially viable. However, in order to develop a rounded practice that fully exploits the benefits of CAD/CAM technologies the designer must understand, at least in part, the technical aspects of the technologies used (Kavanagh, 2008). Designers cannot be totally divorced from the processes of production but must engage with the technology, mediated through a technician if necessary, for long enough to allow tacit knowledge to evolve. This requires institutional systems that allow this technological experience to grow as well as a design methodology that cycles between material and virtual methods so that whole body knowledge of materials and processes can develop.

By dissolving the boundary between design and technology, moving fluidly between production modes as appropriate, the textile designer can become more than creator of functional, commercial products. The application of art & design perspectives and methods, with their underpinning embodied knowledge, to computer-based technological processes can expand both the outputs from and the discourse surrounding these technologies beyond purely functional parameters, suggesting alternative futures where beauty, utility and intuition all play a role.

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Appendix 5

Catalogue of dissemination and networking activities

Role: N&R = Networking & research, PoP = Poster Presentation, OP = Oral presentation, PaP = Paper presentation, GE = Group exhibition participant, SE = Solo exhibitor

Conferences & symposia			
Textiles & fashion design			
Date	Organiser & location	Title	Role
11/11/05	University College for the Creative Arts, Farnham	2121 Nuno: the textile vision of Reiko Sudo	N&R
11/04/06	London College of Fashion, London	Digital Fashion	N&R
21/04/06	Textile Institute, London	Innovation Seminar	N&R
15/09/06	Design Plus & West Focus, RIBA, London	How smart are we? The evolution of textiles, technologies and the consumer	N&R
06/02/07	UMIST, Manchester	3-D Textiles & their applications	N&R
12-14/06/07	Messe Frankfurt, Germany	Techtextil	N&R
14/09/07	Constance Howard Research Centre in Textiles, London	Touch, Texile, Technology: Collaboration across Europe	N&R
21/05/08	The National Gallery, London	Enfolded Meanings: Cloth, body, culture, art	N&R
12/09/08	Constance Howard Research Centre in Textiles, London	Archive Fever 2: Building a Virtual Archive: Collections in the making	N&R
23-24/10/08	Textile Futures Research Group & ICA, London	What future for living textiles?	N&R
18-21/11/08	The Textile Institute, Hong Kong	The 86th Textile Institute World Conference – Fashion & Textiles: Heading towards new horizons	N&R
29/04/09	The Association of Fashion & Textiles Courses	The Research Event	OP
30/04/09	Iniva, London	Second Skins: Cloth & Difference	N&R
03-04/11/10	The Textile Institute, Manchester	The Textile Institute Centenary Conference – Textiles: a Global Vision	PaP

Conferences & symposia (continued)			
'Smart' technologies & Materials			
Date	Organiser & location	Title	Role
22/11/05	MaDE, The Institute of Materials, London	Nanotechnology – Is small Beautiful?	N&R
25/05/06	Smart.mat, The Institute of Materials, London	Smart composites workshop	N&R
29/11/06	MaDE, The Institute of Materials, London	Over the horizon: to infinity & beyond	N&R
06/06/07	MaDE, The Institute of Materials, London	Working with Nature – Green Design Polymers	N&R
12/05/08	UCL, Kings College London & EPSRC, London	New Materials, New Technologies: Innovation, Future and Society	N&R
03/11/08	UCL, Kings College London & EPSRC, London	New Materials, New Technologies: Innovation, Future and Society	N&R
27-29/10/09	Intertech & Pira, Germany	Plastic Electronics Conference 2009	PoP
Applied Disciplines			
Date	Organiser & location	Title	Role
14/10/05	V&A, London	Import/Export. How global is design?	N&R
01/12/05	MaDE, The Institute of Materials, London	At the heart of the matter – Medical Devices Workshop	N&R
20/06/06	London Architecture Biennale, London	Architecture for humanity	N&R
25/06/06	London Architecture Biennale, London	Pecha Kucha	N&R
10-12/06/06	Colston Research Society Symposium, University of Bristol, Bristol	Adaptive Structures Symposium	PoP
7/03/07	University College Falmouth & Metropolitan Works, London	Digital explorers II – Autonamatic	N&R
08/09/07	TATE, London	Softspace: Contemporary interactive environments	N&R
01/03/08	Freud Museum & UCL, London	Too Hot to Handle? Thinking about touch in the psychotherapeutic space	N&R
07/05/08	University College for the Creative Arts & RIBA, London	Memory and Touch: an exploration of textural communication	N&R
28/10/08	MaDE, The Institute of Materials, London	After the Big Idea: from conception to market	N&R
22/06/09	The Architecture Foundation & TATE, London	Architecture + Art: Crossover and collaboration	N&R
26/06/09	University of the Creative Arts, Farnham	Surface Tensions	N&R
06/10/09	Dialogues in Design, RCA, London, London	Where is the Surface?	OP
10/10	Design London, London	Pecha Kucha	OP

Symposia & workshops			
Design & Research Process			
Date	Organiser & location	Title	Role
23/01/06	Centre for Learning & Teaching in Art & Design, London	Creative Thinking Workshop	N&R
14/12/06	Centre for Learning & Teaching in Art & Design, London	Drawing on the writing hand	N&R
17/07/08	RCA & Middlesex University, London	Invitation to Play: an informal colloquium to explore the ludic in arts practice, teaching and learning	N&R
20/01/10	Materials KTN & the R&D Society, London	Moving design upstream in Research & Development	N&R

Trade fairs			
Date	Title	Location	Role
19-21/09/06	Premier Vision, Expofil, Mod'Amont, Indigo	Paris, France	N&R
12-14/06/07	Techtextil	Frankfurt, Germany	N&R
09/2008, 2009 & 2010	100% Design	London	N&R

Work place visits & meetings with experts		
Date	Contact & organisation	Nature of business & location
24/03/06	F. Ciment (Pleating) Ltd	Industrial textile pleating, Potters Bar
20/06/06	Avanti Architects	Architecture, London
12/02/2007	Zoe Laughlin & Mark Miodownik @ The Materials Library, Kings College	Materials science, London
16/05/07 26/10/07 06/11/07	Dr. Raymond Oliver, Cenamps	Science & innovation, nanomaterials, Newcastle
09/11/07	Prof. Eric Yeatman, Imperial College	Micro & electrical engineering, London
29/11/08	Reiko Sudo, Director @ Nuno	Textile design & production, Tokyo, Japan
04/12/08	Katsuhiro Inoue, President @ Inoue Pleats Co., Ltd	Industrial textile pleating, Tokyo, Japan
10/12/08	Kozo Tanaka, Factory manager @ Inoue Pleats Co., Ltd	Industrial textile pleating, Fukui Japan
12/12/08	Kayuzo Onoyama	Textile Artist, Osaka, Japan
12/12/08	Keiko Kawashima, Curator @ Gallery Gallery	Applied Arts Gallery, Kyoto, Japan
01/05/09	Mark Garcia, writer & lecturer @ RCA	Architecture, London
05/05/09	Arantza Vilas, Director @ Pinaki Studios	Textile design & production, London

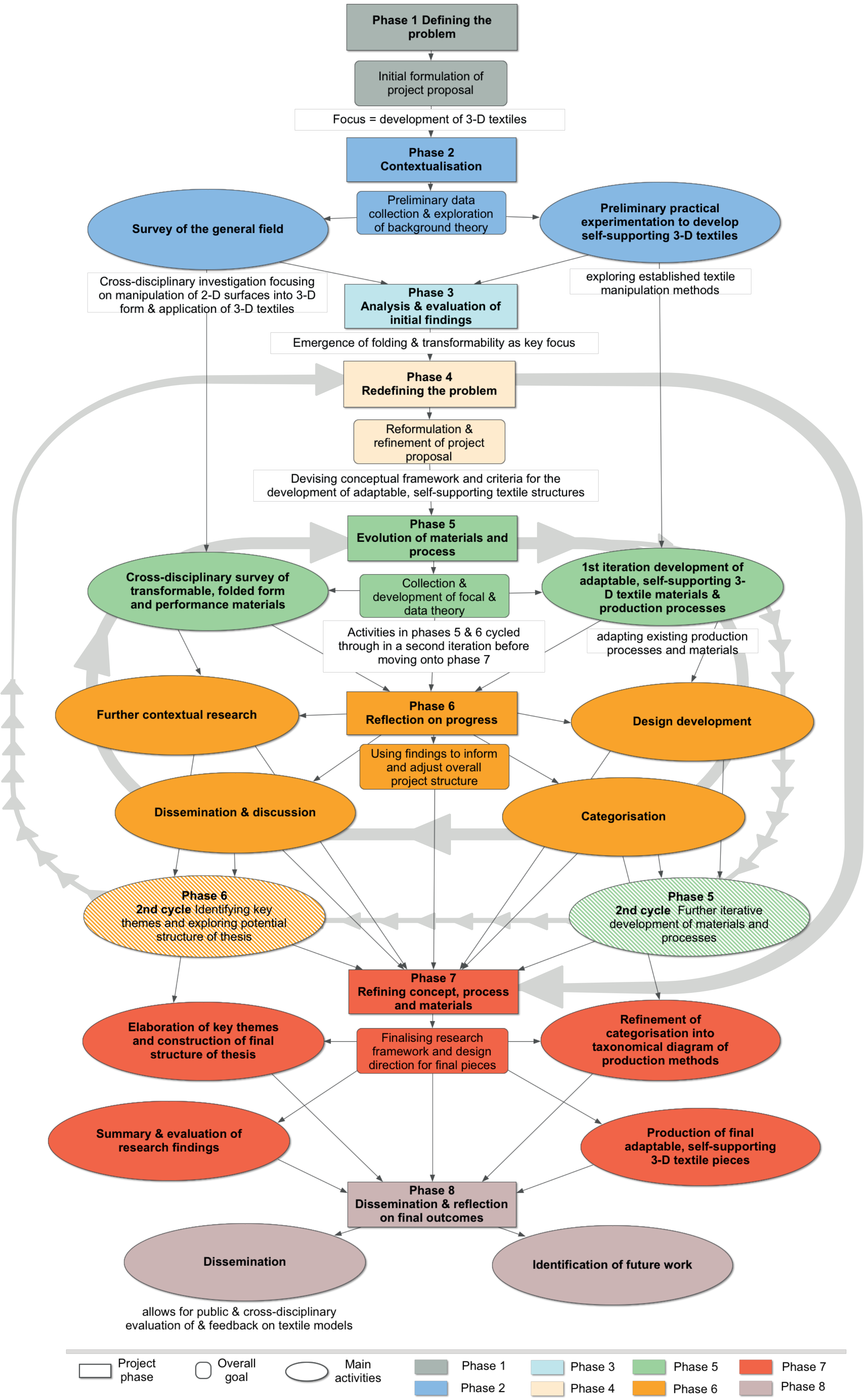
Collaborative projects		
Date	Project title, focus	Team members
23/01-06/03/06	Umbro. Sportswear design	RCA mens & womenswear fashion designers, accessories and textile designers
05/10/10-01/07/11	Innovation, Entrepreneurship and Design. Design of service, space and business model	Imperial College MBA students, RCA fine artist and designer

Exhibition presentations			
Date	Venue	Title	Role
28/04-04/05/11	Jays Mews Entrance Gallery, RCA	Structural Textiles: Adaptable form & surface in three-dimensions	SE
11/09	Lower Gulbenkian Gallery, RCA, London	A Selection. Research RCA Work	GE
01/09	Upper Gulbenkian Gallery, RCA, London	Fashion & Textiles Interim Show	GE
07/08	UK Government Treasury Building, London	Design Means Business	GE
01/08	Upper Gulbenkian Gallery, RCA, London	Fashion & Textiles Interim Show	GE
01/07	Upper Gulbenkian Gallery, RCA, London	Fashion & Textiles Interim Show	GE
01/06	Upper Gulbenkian Gallery, RCA, London	Fashion & Textiles Interim Show	GE

Appendix 6

Diagram of research process

Opposite is a diagram outlining the research process. A more detailed diagram including the specific methods used is attached separately as a digital file named Detailed Research Process Diagram.pdf.


Phase 1 Defining the problem
Initial formulation of project proposal
Focus = development of 3-D textiles
Phase 2 Contextualisation
Preliminary data collection & exploration of background theory
Survey of the general field
Preliminary practical experimentation to develop self-supporting 3-D textiles
Cross-disciplinary investigation focusing on manipulation of 2-D surfaces into 3-D form & application of 3-D textiles
exploring established textile manipulation methods
Phase 3 Analysis & evaluation of initial findings
Emergence of folding & transformability as key focus
Phase 4 Redefining the problem
Reformulation & refinement of project proposal
Devising conceptual framework and criteria for the development of adaptable, self-supporting textile structures
Phase 5 Evolution of materials and process
Cross-disciplinary survey of transformable, folded form and performance materials
Collection & development of focal & data theory
1st iteration development of adaptable, self-supporting 3-D textile materials & production processes
Activities in phases 5 & 6 cycled through in a second iteration before moving onto phase 7
adapting existing production processes and materials
Further contextual research
Phase 6 Reflection on progress
Design development
Using findings to inform and adjust overall project structure
Dissemination & discussion
Categorisation
Phase 6 2nd cycle Identifying key themes and exploring potential structure of thesis
Phase 5 2nd cycle Further iterative development of materials and processes
Phase 7 Refining concept, process and materials
Elaboration of key themes and construction of final structure of thesis
Finalising research framework and design direction for final pieces
Refinement of categorisation into taxonomical diagram of production methods
Summary & evaluation of research findings
Production of final adaptable, self-supporting 3-D textile pieces
Phase 8 Dissemination & reflection on final outcomes
Dissemination
Identification of future work
allows for public & cross-disciplinary evaluation of & feedback on textile models
Project phase
Overall goal
Main activities
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
Phase 8

Phase 1 Defining the problem
Initial formulation of project proposal
Focus = development of 3-D textiles using silk-screen printing combined with other textile manipulation techniques
Phase 2 Contextualisation
Preliminary data collection
Cross-disciplinary exploration of background theory focusing on manipulation of 2-D surfaces into 3-D form, application of 3-D textiles as well as textile materiality and functionality
Survey of the general field
using methods including
attendance of conferences and symposiums
visit to UK based small scale industrial pleating facility
literature survey - shaped & 'smart' textiles focus
exhibition visits
Preliminary practical experimentation to develop self-supporting 3-D textiles
using established textile manipulation methods
stitched
tied
printed
card moulded
recording findings in
reflective journal
data cards documenting production process
Phase 3 Analysis & evaluation of initial findings
Emergence of folding & transformability as key aspects of the study
Phase 4 Redefining the problem
Reformulation & refinement of project proposal
Devising conceptual framework and criteria for the development of adaptable, self-supporting textile structures
Phase 5 Evolution of materials and process
Collection & development of focal & data theory
Activities in phases 5 & 6 cycled through in a second iteration before moving onto phase 7
Cross-disciplinary survey of transformable, folded form and performance materials
focusing on
biological models and biomimetics
production processes
architectural use of textile materials
adding to methods used above
literature survey - focus on theories of folding and architectural practice
visit to large scale industrial pleating facility in Japan
analytical drawing and photography
1st iteration development of adaptable, self-supporting 3-D textile materials & production processes
search for specific materials
shop visits
trade fairs
material development
modelling form
paper
card
textile
adaptation of existing production processes
combining printed and moulded manipulation techniques
recording the design process
reflective journal
production process electronic database
creative writing
documentary photography & video
Phase 6 Reflection on progress
Using findings to inform and adjust overall project structure
Further contextual research
consideration of potential application
new developments
Dissemination & discussion
consultation with experts
interim exhibition of work in progress
presentation at conferences and symposiums
Categorisation
preliminary categorisation of folding types & production methods
Design development
imaginative drawing exercises & video production
review of reflective journal & production process database
Phase 5 2nd cycle Further iterative development of materials and processes
combining textile & non-textile materials
creating modular systems
moving towards mono-material construction for easier recycling
Phase 6 2nd cycle Identifying key themes and exploring potential structure of thesis
Phase 7 Refining concept, process and materials
Finalising research framework and design direction for final pieces
Elaboration of key themes and construction of final structure of thesis
Refinement of categorisation into taxonomical diagram of production methods
Summary & evaluation of research findings
Production of final adaptable, self-supporting 3-D textile pieces
Phase 8 Dissemination of & reflection on final outcomes
Dissemination
presentation of research at international conferences
exhibition of PhD work
presentation of research to expert cross-disciplinary practitioners
PhD thesis
allows for public & cross-disciplinary evaluation of & feedback on textile models
Identification of future work
methodological developments
practical developments
Project phase
Overall goal
Main activities
General methods
Specific methods
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
Phase 8

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