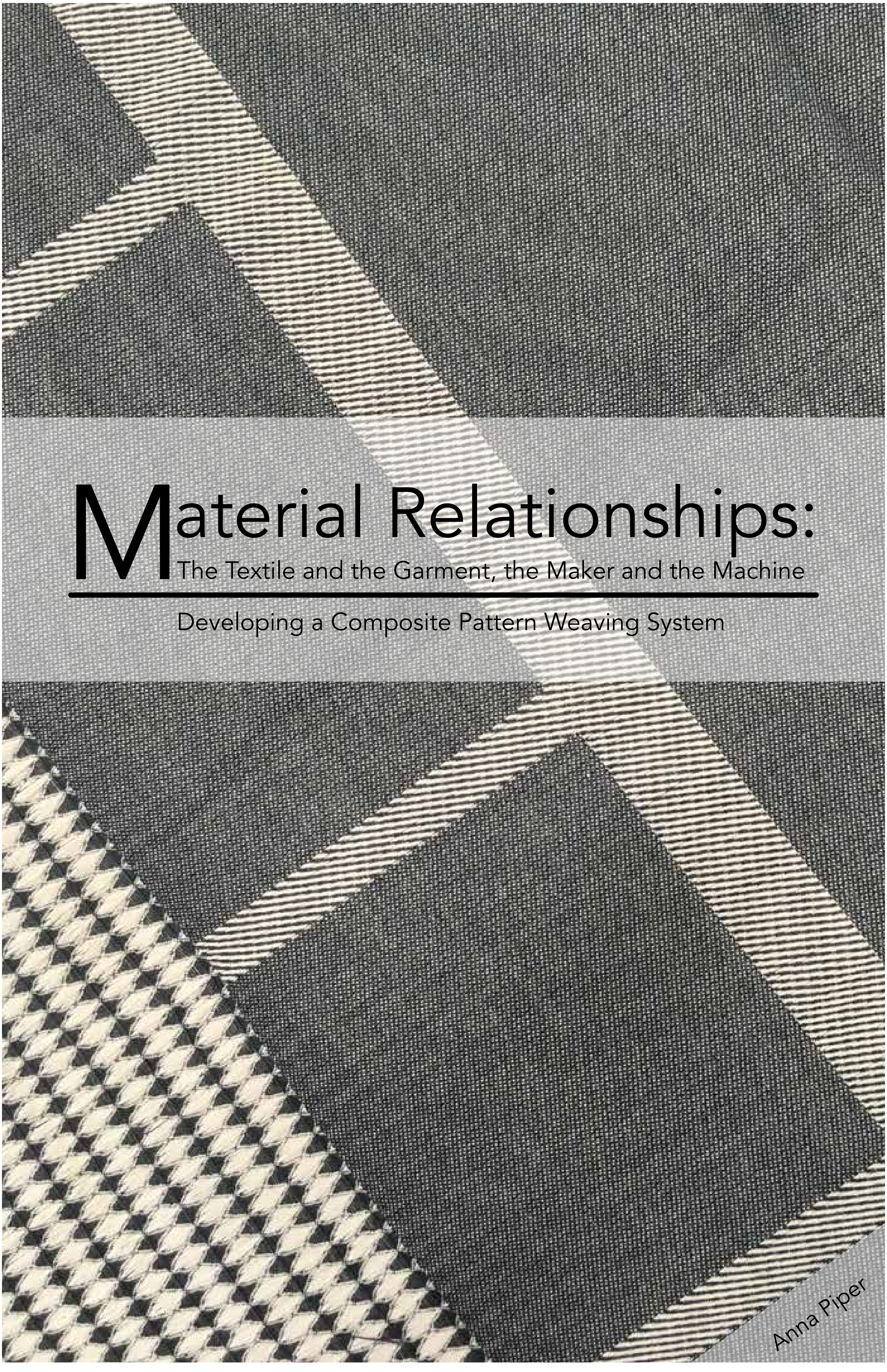


Material Relationships:

The Textile and the Garment, the Maker and the Machine

Developing a Composite Pattern Weaving System

Anna Piper

Material Relationships:
The Textile and the Garment, the Maker and the Machine
Developing a Composite Pattern Weaving System

Anna Piper

A thesis submitted in partial fulfilment of the requirements of
Nottingham Trent University for the degree of Doctor of Philosophy

October 2019

Abstract

This research brings together the disciplines of woven textile design, zero waste pattern cutting and fashion design to form the Composite Pattern Weaving system; an innovative approach to woven garment design and construction which assimilates textile and garment lay-plan design and construction to produce engineered zero waste and integrally shaped woven garments, containing multiple fabric qualities, from a single length of woven textile. The approach challenges conventional textile and fashion design processes and systems by adopting a holistic and simultaneous approach to the design and production of textile and garment components; facilitating the integration of functional and sustainable design strategies to enhance garment durability and longevity through the implementation of a multi-method lifecycle approach to design.

This research adopts the Transitional Design Methodology; an alternative approach of working between traditional and advanced technologies which challenges the constraints of the two modes of production whilst capitalising on their advantages. This cyclical iterative approach emphasises the importance of the relationship between the maker, materials and the machine(s), whilst recognising the potential for a transitional dialogue and knowledge transfer between all aspects of hand and digital production. Employing both modes of production in parallel, the Transitional Design Methodology facilitates a reciprocal relationship whereby concepts, designs and ways of working evolve as the maker moves between modes.

Through the production of zero waste woven garment prototypes using hand and digital weaving technologies, the research establishes new integral shaping techniques and woven garment construction methods to minimise material production, consumption and waste, and identifies some of the limitations of fully-fashioned and composite garment weaving. The garment prototypes embody the learning and knowledge derived through the application of the Transitional Design Methodology. They demonstrate the advantages of working iteratively between hand and digital modes of design and construction to produce innovative (and interconnected) design outcomes, to advance skills and processes, and enhance personal practice.

Contents

6. Functionality: Design Principles and Aesthetic Style 235

Appendices

Illustrations

2. Knowing Through Making

3. Transitional Design

1 Introduction

1 Introduction:

This thesis takes the form of a visual essay, with selected chapters extensively illustrated to capture and communicate the creative process and outcomes, and to make the nature and rigour of the practical work accessible to the reader. The approach responds to the theory that the experiential knowledge that is central to creative practice and derived through physical (sensory) engagement with materials, tools and processes can be impossible to articulate texturally or verbally (Niedderer & Townsend 2014; Malafouris 2005; Polanyi 1966).

1.1 Research Overview

This practice-led research focuses on the development of the Composite Garment Pattern Weaving system (CPW). CPW involves the design and production of engineered zero waste garment patterns (or lay-plans), constructed in a single textile piece on the loom. By constructing the textile and lay-plan simultaneously, the process minimises material production and consumption by reducing cutting, stitching and seams. Through a series of garment prototypes, the research explores the capability of CPW to assimilate multiple fabric qualities and seamless integral shaping within a single textile, tailored to specific garment requirements. Building upon existing Zero Waste Pattern Cutting (ZWPC) approaches, fully-fashioned and seamless knitting techniques as well as Miyake's innovative 'A-POC' and '3D Steam Stretch' concepts (Issey Miyake c.2016), the research offers new opportunities for zero waste and sustainable textile and garment production.

The thesis documents the development and implementation of the Transitional Design Methodology; an iterative process of working in parallel between analogue and digital production methods to exploit the reciprocal exchange of knowledge, skills and ideas. The methodology combines the heuristic approach to design and making advocated by Lehmann, U (2012) and Lawson (2006), with the experimental philosophy of the Bauhaus weavers (Smith 2014) such as Anni Albers, who particularly focussed on "the role of material" (Margetts 2018: 36). Recognising the vital role of hand weaving in developing innovative textiles and applying the technical and manufacturing potential of digital technologies, this integrated digital craft methodology challenges established linear design and production systems (Gwilt 2011: 69). The research offers an alternative (transitional) way to practice and innovate from embodied weaving and sustainable design perspectives.

1.2 Research Terminology

The following terminology is applied throughout the thesis to distinguish between different types of woven garment construction:

Composite Garment Weaving:	whole garments woven in a single component piece, requiring no seaming or construction when removed from the loom. Garments may include integral shaping, multiple fabric qualties and functional panelling.
Composite Pattern Weaving:	zero waste garment lay-plans (or patterns) woven from a single length of cloth, incorporating engineered pattern components that are cut and stitched to construct the garment. Composite patterns include multiple fabric qualities, with cutting lines and seam allowances constructed into the cloth. Individual pattern components may include integral shaping and functional panelling.

Single-piece Garments:	garments constructed from a single component piece (rather than multiple pattern pieces), which is cut, folded and stitched to form the garment. In this research, Composite Pattern Weaving is used in conjunction with single-piece garment construction.
Fully-fashioned Garments:	garments constructed from integrally shaped components that are stitched together. This type of construction is frequently used in knitwear. Woven garments of this type are also referred to as loom-shaped.

1.3 Research Context

This study is informed by three distinct but interrelated research contexts that guide and shape the practice, methodology and theoretical framework – woven garment construction (Technical Process - Chapter 4), sustainable design practices and principles (Sustainability - Chapter 5) and embodied making/understanding (Knowing Through Making - Chapter 2).

Technical Process: the practice responds to the limited research into fully-fashioned, single-piece and composite garment weaving; particularly the development of design-led single-piece garment weaving for fashion applications (Section 4.3). The dearth of research is partly attributable to the absence of advancements in technology and equipment capable of seamless garment weaving (Wang 2011; Jayaraman & Park 2001). The difficulties associated with fashioning and integrally shaping woven fabrics (due to its interlaced multi-yarn construction (Jayaraman & Park 2001)) (Section 4.6.3), as well as the complexity of assimilating the design of 2D textile and 3D garment, are also contributory factors.

Research into fully-fashioned, single-piece and seamless garment weaving has tended to focus on the integration of intelligent technologies for technical, functional and medical applications (examples include Rathnayake, Piper & Townsend 2012; Osborne 2010; Jayaraman & Park 2001; Jayaraman, Park & Rajamanickham 2000); developing methods for seamless construction and on-loom shaping of armholes and sleeves (Section 4.3.2). A small number of studies consider fashion applications (Wang 2011;

Wang, Ng, Hu & Szeto 2009; Ng, Wang, Hu & Szeto 2010; Ng, Hu, Szeto & Wang 2007; Singh Sawhney 1972). These studies employ digital Jacquard looms to construct garments (dresses) from a single woven tube, shaped using a single stretch fibre (such as elastane) used in the weft. Technical process development (rather than design aesthetics) is at the forefront of the research.

Further examples of loom-shaped garment weaving can be found in the craft realm, where designers including Lottie Dalgaard and brands such as Manonik and friends of light (Section 4.3.1), use traditional hand weaving and yarn manipulation techniques to produce shaped garment components that are constructed off-loom into bespoke jackets and dresses. Miyake's 'A-POC' concept (Issey Miyake c.2016) is the only identified composite garment range to be introduced into the contemporary fashion market. Garments are constructed as double-layered 2D pieces that can be cut out in multiple ways to suit the consumer (Section 4.3.3).

Sustainability: cutting waste in standard cut-and-sew garment production averages 15-20% (Rissanen & McQuillan 2016; Rissanen 2013; Brown 2013a; McQuillan 2010; Fletcher 2008; Abernathy, Dunlop, Hammond and Weil 1999). ZWPC is at the forefront of waste-elimination in fashion design (prominent examples include the work of Holly McQuillan, Timo Rissanen and David Telfer), aiming to "design out" (DEFRA 2013: 9) waste by using 100% of a length of fabric (Section 5.6.3).

Whilst Rissanen (2013) reasonably asserts that cut-and-sew construction, alongside the production of rectangular pieces of cloth, will continue its dominance, in knitwear fully-fashioned and whole garment production techniques are used on an industrial scale (Section 5.6.1). These garment construction methods facilitate the production of integrally shaped pieces as well as single-piece and composite garments. They can reduce material production and consumption and are recognised as a form of zero waste fashion design (Taylor & Townsend 2014).

It is acknowledged that fully-fashioned, single-piece and seamless composite garment weaving is unlikely to be "as flexible and controllable as 'whole garment' knitting technology" (Thomas 2009:151). However, there is potential for woven garment construction techniques to be applied to minimise waste production and material consumption, reduce manufacturing and construction costs and labour (Lefferts 2015;

Scanlon 2004), enhance durability and functionality for the purpose of garment longevity, as well as facilitating small-batch, responsive and customised production (Allwood, Bocken, Laursen & De Rodriguez 2006: 30). Furthermore, the simultaneous production of fabric and garment demanded by these techniques requires an integrated design approach that fosters a more sustainable fashion system (Gwilt 2011); by "placing the designer in an influential position" (Ibid: 67) and allowing him/her to "design, plan and create a new garment design in tandem with the integration of sustainable strategies" (Ibid: 69).

Knowing Through Making: research into the relationship between the mind, body and the physical (made) object, from the fields of cognitive science, neuroscience and philosophy, is increasingly informing design and craft research and practice (see Groth 2017; Leinikka, Houtilainen, Seitamma-Hakkarinen, Groth, Rankanen & Mäkelä 2016; Lehmann, U 2012). The act of making is a sensory experience, whereby the craftsperson engages directly with materials, tools and processes (Groth 2017; McCullough 1997; Albers 1961) (Section 2.3.2). Through this tactile and haptic experience, the maker (or craftsperson), over time, develops the knowledge and ability to skilfully manipulate the materials and tools of their discipline. Craft knowledge has been categorised as explicit (objective scientific facts and technical taught principles that can be articulated textually or verbally) and tacit (subjective knowledge gained through experience such as intuition, understanding and 'knowing') (Pallasmaa 2009; Polanyi 1966), with the knowledge and understanding derived through physical material and process engagement absorbed by the maker (Section 2.3.1). This 'embodied' knowledge can be difficult (even impossible) to put into words and therefore remains "largely tacit" (Niedderer & Townsend 2014: 633).

The role, importance, acquisition and application of embodied (or tacit) knowledge in craft practice and the process of making, has recently become an area of interest for researchers, practitioners and educators. Investigations into the relationship between making and knowing (see Groth 2017; Lehmann, U 2012), documenting and communicating tacit knowledge (see Lehmann, A 2012; Valentine 2011), advancing craft through research (see Niedderer & Townsend 2014; Numkulrat 2012), and personal analysis of technical and tacit experience expanding practice (see Auch 2016; O'Connor 2007) contribute to the development of new craft-based methodologies and the advancement of (an individual's) craft practice(s), inspiring novel ways of capturing and communicating practice-led research.

The nature of the relationship between knowledge, making, skills acquisition and haptic sensory engagement with materials, tools and processes is particularly pertinent in an era where craftspeople are introducing digital tools and technologies into their practice (Section 2.4). These tools and technologies can distance the maker from materials and processes (Pallasmaa 2009; Cardoso 2008; McCullough 1997; Dormer 1994); replacing direct physical material and process manipulation with on-screen digital programming, virtual manipulation and simulation of materials and production, with 'hands-off' computer-controlled production. In addition to a growing body of research exploring how these technologies can enhance and extend creative practice (Nimkulrat, Kane & Walton Eds. 2016; Braddock Clark & Harris 2012), researcher-practitioners are also examining how embodied knowledge derived through hands-on making can assist in making the transition from hand to digital production (see Piper & Townsend 2015; Taylor 2015; Philpott 2012) (Section 2.5). This enables diversification and innovation in industrial production and sustains textile traditions (see Parry-Williams 2015; 2007).

1.4 Initial Proposal: Composite Garment Weaving

The original intention of this research was to develop a Composite Garment Weaving system (CGW) to construct and integrally shape garments on the loom. Building on my experience of producing "flat-packed" (Aldrich 2008: 131) garments (with no integral shaping) (Section 5.3.1), the proposed research aimed to explore the garment shaping capabilities of 3D craft weaving techniques (Section 4.4.2). The proposal responded to and was inspired by the diverse range of 3D and shaped woven textiles being produced by craft practitioners (see the work of Ann Richards (2012), Philippa Brock (Hemmings 2012) and Angharad McLaren (2015)). These textiles use yarn and weave structure manipulation techniques, and combine traditional and advanced fibres to create dynamic 3D pleated and folded fabric forms. These techniques and textiles highlight the limitations of the of existing investigations into single-piece, fully-fashioned and composite garment weaving undertaken to date (Section 4.3), by displaying the capacity for a different type of garment shaping and forming that does not rely solely on stretch.

1.5 Reframing the Research: Composite Pattern Weaving

Composite Garment Weaving (CGW) was reinterpreted through the development of a Composite Pattern Weaving (CPW) approach. The intended research into CGW required hand and digital weaving looms for technical testing and garment production. The integration of hand and digital practices was also intrinsic to the research's Transitional Design Methodology (Section 3.3). In 2015, a TC2 digital Jacquard sample loom was procured by Nottingham Trent University (NTU), for use alongside existing hand and digital equipment. However, unforeseen installation complications postponed its availability for the research until November 2017, impeding progress.

In CGW, prototypes are designed specifically for the loom on which they will be produced. The type of warp yarn, lifting mechanism and warp width are critical factors in the design process. Whilst integral shaping techniques had been developed using the hand and Jacquard power loom early on in the research (Section 7.3), the assimilation of integral shaping into composite garments is complex and time consuming; requiring significant testing and development. By Summer 2017 it was not possible to delay garment design and production any further and the decision was made to shift the focus of the research, concentrating on the development of a Composite Pattern Weaving system; producing engineered zero waste garment patterns (lay-plans) constructed in a single piece on the loom.

The approach offers greater flexibility in garment design, with a wider range of garment types and styles being possible, whilst adhering to the original principles of minimising material consumption and eliminating cutting waste. It also allows for the integration and assimilation of other sustainable design methods and strategies, including designing for recyclability (Section 5.9), durability and longevity (Section 5.8), and builds upon existing ZWPC techniques; facilitating the production of garments containing multiple fabric qualities, integral shaping and seamless functional panelling.

1.6 Research Aims

The research is structured around three principal aims as follows:

Knowing Through Making: to investigate the role that embodied weaving knowledge plays in informing textile design innovation by recording and analysing the iteration between, and transition from, analogue to digital production, through reflective practice.

Technical Process: to explore the design potential of composite pattern weaving and single-piece garment weaving as an alternative to conventional cut-and-sew construction, by developing 3D prototypes that test and demonstrate the flexibility of the Composite Pattern Weaving system.

Sustainability: to establish methods of minimising cutting waste and reducing material production in woven garment design and construction, through the development of garment prototypes that explore form, function and multi-functionality as design imperatives.

Each aim responds to and is underpinned by a specific research context (outlined in Section 1.3) and is aligned to a dedicated chapter in the thesis (detailed in Section 1.8). These aims provide a framework for the investigation; informing and directing the practice, research methods and theoretical foundation. The aims are iterative and complementary – individual aims are not achieved in isolation but in conjunction with each other, reflecting the integrated transitional ethos that is at the heart of my practice.

1.7 Transitional Design: Research Methodology

The catalyst for this research was my production of 'flat-packed' garments using hand and digital looms during my postgraduate study in MA Textile Design Innovation (2013), and my initial experimentation with yarn and woven structure manipulation techniques during my undergraduate degree in (woven) BA Textile Design (2009-2012). This established expertise in hand weaving and my relative inexperience of working with digital production techniques laid the foundation for the Transitional Design Methodology (Chapter 3). It is important to note at this stage that whilst I was employing hand and digital weaving techniques for the production of woven garments, I have no formal experience or training in fashion design – I am a textile designer specialising in woven construction.

As a hand weaver I had developed knowledge of yarn characteristics, weave structures and weaving techniques through experimental sampling and direct physical engagement with materials and processes. As I moved into digital Jacquard weaving, I was able to draw upon some of this pre-learned/practiced knowledge and understanding (Niedderer & Townsend 2014; Philpott 2012; Dreyfus & Dreyfus 1986), but experienced some difficulties replicating the types and quality of textiles produced on the hand loom. I became frustrated by my inability to: control the process, to physically interact with the textile being constructed in front of me; to respond and react to errors in the design, and to achieve the desired/intended outcome. Over time, by engaging with digital programming and Jacquard production, alongside my experimental hand weaving, I became more efficient and proficient at producing designs and predicting/envisaging digitally woven outcomes.

It was not until I analysed the reflective journals from my MA studies, during the early stages of this research (2014), that I began to understand and realise the relationship between my hand and digital practices. It became apparent that they were not as discrete as I had imagined - they were interdependent, with experiences and outcomes informing one another; ideas for digital weaving were evolving during hand weaving and vice versa (Section 3.3.1; Journal Excerpt 3.1).

The Transitional Design Methodology is predicated on this realisation – that my established approach to hand and digital practice was iterative and contingent on hand and digital weaving taking place in parallel. This practice-led methodology employs a multi-method approach to research, it operates within a framework of creative experimental first-person action research (Trullen & Torbert 2013; Reason & Bradbury 2001) and is guided by Schön's principles of "Reflection in Action" and "Reflection on Action" (1991) (Section.3.4). The implementation and development of the methodology within this study is inspired and underpinned by a number of traditional and contemporary design approaches and theories, in particular the work of the Bauhaus weavers (Anni Albers and Gunter Stolzl) (Section 2.5.1), Ulrich Lehmann's concept of "Making as Knowing" (2012), and Lawsons "parallel lines of thought" (2006) (Section 3.6).

At the heart of Bauhaus Weaving theory is the belief that "handwork" (Smith 2014: xvii) is central to innovative practice. Albers and Stolzl experimented extensively with hand weaving techniques to develop fabrics for industrial production. Working on the hand loom to "generate formal, technical, and material developments in design" (Ibid: 48), for the purpose of exploiting the potential of mechanised production and establishing its parameters; hand weaving was considered to be a medium for thinking, with Albers declaring that:

> […] the way towards mass production must come through an understanding of the craft.
>
> (Ibid: 45)

Whilst the Bauhaus weavers were highly successful in their endeavours (i.e. the development of woven fabrics for industrial (mass) production and application) and raised the status of the craft of weaving (Smith 2014), their theories position hand weaving at the forefront of a linear process of development and production; limiting the possibility of a reciprocal exchange of knowledge, understanding, ideas and skills that can be achieved by working between analogue and mechanised production.

As debates relating to the use and integration of digital technologies in craft practice shift from focussing on the nature of the relationship between the maker, the digital tool and the final artefact (see Cardoso 2008; McCullough 1997; Dormer 1994; Pye 1968), to the integration of craft knowledge with advanced technologies to explore their creative potential, a new form of craft practice has emerged – digital craft (Section 2.4). Digital technologies are no longer perceived purely as assisting the handmade by automating and accelerating production, facilitating reproducibility and small-batch production (Frayling 2011), they are enabling new ways of working, thinking and communicating craft practice, resulting in "new kinds of practice" (Harris 2012; 97). Craft practitioners are developing "creative partnerships with digital technology" (Kane 2013: 290) by combining hand and machine processes and applying craft-based methodologies to their use of digital tools to challenge traditional perceptions of craft, and push the boundaries of materials and processes to advance outcomes.

> […] innovative outcomes are […] ultimately achieved through collaborative, human/machine interactions involving tacit knowledge, skills, and trust.
>
> (Townsend 2016: 189)

Craft and technology's compatibility and potential to transform and enhance creative craft practice, by facilitating innovation and the development of new methodologies, is increasingly dominating craft and design research (Campbell 2016). To date, this area of research has emphasised a traditional linear transition between hand and digital production (Section 2.5); with hand production preceding digital as a means of acquiring the material and process knowledge required to negotiate technologies and conceptualise designs (examples include Taylor & Townsend 2014; Philpott 2012).

In contrast, this practice-led research challenges and presents an alternative to the established linear approach to the integration of analogue and digital production through the development, application and testing of a transitional methodology, with hand and digital weaving taking place in parallel, to capitalise on the constraints and affordances of the two modes of design conceptualisation and production. Furthermore, this involves the integration, adoption and adaptation of methods from a range of disciplines and practices including fashion design, zero waste pattern cutting and whole garment knitting (Section 3.7).

> One cannot minimize the value of designers who move across fields with which they have had less experience. Their lack of knowledge of specifics may actually help them to develop exciting new, untried approaches because they have no preconceptions about what cannot be done.
>
> (Watkins & Dunne 2015: 2)

In his essay 'Making as Knowing: Epistemology and Technique in Craft' (2012), which uses weaving as a metaphor to consider the application of *episteme* and *techne* in textiles, Lehmann promotes the cross-disciplinary transfer and application of techniques, skills and materials, and the restructuring of processes as a way to challenge existing thinking and generate new knowledge. This demands a departure from established rules and traditions of making, by deconstructing or reversing existing '*techne*'. The analysis of existing *techne* (craftsmanship/making), according to Lehmann, can lead both to innovations in practice and the creation of episteme (knowing/true knowledge). In this research the cross-disciplinary transfer and analysis of practice is aligned with Lawson's "parallel lines of thought" (2006), whereby multiple lines of thought (or enquiry) are pursued simultaneously; thinking about a design in different ways from different perspectives to expand ideas, find creative solutions and innovate (Section 3.6).

> The ability to think along parallel lines, deliberately maintain a sense of ambiguity and uncertainty and not to get too concerned to get to a single answer too quickly seem to be essential design skills.
>
> (Lawson 2006: 298)

This parallel-thinking approach is expanded in the Transitional Design Methodology (Chapter 3), to also encompass making, in a process where hand and digital design and production take place in tandem, with "Reflection in Action" and "Reflection on Action" (Schön 1991) central to informing future practice. By adopting a heuristic cross-disciplinary approach to design (Section 3.7), whereby hand and digital methods and fashion and textiles processes are combined, new ways of working and thinking about design, construction and the integration of sustainable practice are stimulated. As the maker moves between modes of production, concepts, new ways of working and designs can evolve. Ideas are conceived and interrogated within the limitations of one process, and are transferred, expanded and developed to exploit the advantages of the other. Consequently, the hand and digital Jacquard processes become intertwined and are mutually beneficial, with digital Jacquard outcomes initially relying on embodied craft knowledge and hand woven outcomes being equally dependent on the experiential knowledge of digital construction.

The research is, therefore, concerned with the process of design as much as the practice outcomes. As well as exploring and highlighting the sustainable design potential offered by integrating weaving with fashion design processes, the experimental outcomes are also a vehicle for understanding my practice and the process of knowledge making. As such, the woven garment prototypes are not presented as refined finalised designs, instead they are a starting point for the development of the zero waste pattern weaving concept, whilst simultaneously being an expression of my own learning, understanding and knowledge. They are the physical embodiment of the implementation and evolution of the Transitional Design Methodology. Reflecting the interconnected and evolutionary approach to sustainable design and practice, advocated by the emergent (and similarly named) Transition Design movement (Section 3.7.2)[1], the Transitional Design Methodology adopts an open and iterative approach, rather than "linear, cause-and-effect thinking" (Irwin 2015: 234), to develop new visions, knowledge, theories and mindsets (Irwin 2015; Irwin, Kossoff & Tonkinwise 2015) that challenge existing (unsustainable) textile and fashion design and production models.

1.8 Thesis Structure

Chapter 2 - 'Knowing Through Making: The Role of Embodied Knowledge in Hand and Digital Design and Production' provides the theoretical framework for the study, exploring the relationship between theoretical (explicit) and practical (experiential) knowledge in craft practice and applying this to the process of CPW. Drawing upon Dreyfus and Dreyfus' stages of "Knowledge Acquisition" (1986), Ulrich Lehmann's concept of "Making as Knowing" (2012) and Malafouris' Material Engagement Theory (2013), it considers how the knowledge derived through the experience of hands-on making can aid the transition from hand to digital weaving. The chapter lays the foundation for the Transitional Design Methodology (Chapter 3) and provides the rationale for the 'visual' format of the thesis.

Chapter 3 – 'Transitional Design: Methods and Methodology' describes and defines the Transitional Design Methodology devised and implemented throughout the study; informed by craft, design thinking and sustainability theories and approaches including Lawson's "parallel lines of thought" (2006), Lehmann's "Making as Knowing" (2012) and the sustainable design strategies of zero waste pattern cutting and whole garment knitting. It outlines the identification, evolution and implementation of this iterative approach to design and production in response to the changing parameters of the research, before discussing the selection and application of reflective, evaluative and documentary methods.

---

[1] The Transition Design movement emerged concurrently but independently of this research and the development of the Transitional Design Methodology. As a heuristic and evolutionary approach to sustainable design, advocating cross-disciplinary collaboration and self-reflection, Transition Design has discernible connections with the Transitional Design Methodology that are expanded upon in Section 7.3.2.

Chapter 4 – 'Composite Pattern Weaving: Technical Context' reviews the existing examples of single-piece, fully-fashioned and composite garment weaving found in craft (such as Manonik 2017; Lee 2016; Dalgaard 2012), functional (see Jayaraman et al. 2000; Osborne 2010) and commercial (see Miyake in Vitra Design Museum 2001) woven production, before outlining the complexities of integrally shaping woven textiles and garments. Comparisons are made between the developments in woven garment construction relative to the advancements seen in knitted garment construction, with knitting methods providing a blueprint for technique and process development. A number of woven construction techniques are also identified as a starting point for the technical investigation.

Chapter 5 – 'Sustainability: A Multi-method Lifecycle Approach' sets out the sustainability criteria and priorities for the research, before summarising the sustainability debates that have informed and inspired the development of CPW. There follows an analysis of the existing models and strategies employed by designers and researchers seeking to limit the environmental impact of clothing manufacture and disposal, by addressing the issue(s) of pre and post-consumer fashion waste. This includes McQuillan and Rissanen's (2016) extensive zero waste fashion design practice, and WRAP's (2017)recommendations for extending garment lifetimes by enhancing garment durability and quality. Throughout the chapter the potential impacts of the work and opportunities for CPW are considered within the context of sustainable and zero waste textile and fashion design.

Chapter 6 – 'Functionality: Design Principles and Aesthetic Style' begins by outlining the functionality principles applied in the design and development of garments produced using the CPW system. The principles are divided into two categories – functional durability and aesthetic desirability. They encompass wear and tear, comfort and fit, colour, pattern and styling. The chapter goes on to explain the importance and influence of these factors on technique development and garment design, as well as discussing the important role the body has in the design process. A summary of the significant design philosophies (Bauhaus weaving, Constructivist design and Japanese fashion design) that have impacted upon and inspired my approach to design (in this and previous research) complete the chapter.

Chapter 7 – 'Composite Pattern Weaving: Technical Application and Outcomes' concentrates on the development of technical processes and garment prototypes. The chapter classifies the types/methods of woven production used in the research – hand, digital and hybrid. It outlines the constraints and advantages of each mode of production, providing full specification details of the looms used to produce the prototypes. Individual sections describe in detail the design and production of each garment, including discussion and evaluation of the sustainability and functional design principles applied to each garment, followed by an appraisal of the garment design and the technical process potential (identifying possible improvements and areas for development).

Chapter 8 – 'Conclusion: Research Reflections, Findings and Future Research' is broken down into the review of and reflections upon the CPW practice and the Transitional Design Methodology; outlining the technical limitations and potential of the CPW system, as well as highlighting the significance of the maker's relationship with the tools (or machines) of their craft in the advancement of innovative practice. The knowledge and insights gained through garment prototype development, along with reflection on skills, experiences and outcomes, inform a series of practical recommendations for those undertaking research into fully-fashioned and composite garment weaving. By uncovering some of the challenges associated with integrally shaping woven fabrics, and recognising the limitations of my own practice, areas for further technical investigation are identified.

1.9 Thesis Format

In this thesis images appear alongside the text and are accompanied by quotations and captions to support the 'visual' narrative. This integration of pictorial and textual narratives builds upon Ann-Sophie Lehmann's assertion that images are capable of mediating "between the domains of implicit and explicit knowledge" (2012: 13), whilst recognising that visual outputs alone may not fully convey design thinking (Pedgley 2002: 466) (Section 2.7).

Given the importance of and emphasis placed on self-reflection and reflective practice in action research and in the Transitional Design Methodology, the chapters (excluding Chapters 4 and 6) are accompanied by reflective journal excerpts and sketchbook annotations. These reflective records offer the reader a deeper insight into the creative process; evidencing and capturing my thinking, learning, decision-making and problem-solving, as well as recording my analysis of materials, processes, experimentation and outcomes. The excerpts are referenced in the text but appear at the end of each chapter, to avoid disrupting the flow of the discussion.

1.10 References

ABERNATHY, F, H. DUNLOP, D. HAMMOND, J. & WEIL, D. (1999). *A Stitch in Time: Lean Retailing and the Transformation of Manufacturing - Lessons From the Apparel and Textile Industries*. Oxford: Oxford University Press.

ALBERS, A. (1961). *Albers: On Designing. Connecticut*: Wesleyan University Press.

ALDRICH, W. (2008). *Metric Pattern Cutting for Women's Wear*. (5th Edition). Oxford: John Wiley & Sons.

ALLWOOD, J, M. BOCKEN, N. LAURSEN, S, E. & DE RODRIGUEZ, C, M. (2006). *Well Dressed?: The Present and Future Sustainability of Clothing and Textiles in the United Kingdom*. Cambridge: Institute for Manufacturing.

AUCH, M. (2016). 'The Intelligence of the Hand'. In: NIMKULRAT, N. KANE, F. & WALTON, K. (Eds.). (2016). *Crafting Textile in the Digital Age*. London: Bloomsbury. pp. 61-73.

BRADDOCK CLARKE, S, E. & HARRIS, J. (2012). *Digital Visions for Fashion + Textiles: Made in Code*. London: Thames and Hudson Ltd.

BROWN, S. (2013a). 'Design for Cyclability: Pre-Consumer Waste'. *Textile Toolbox*. Available at: http://www.textiletoolbox.com/posts/pre-consumer-waste/. Accessed: 04 December 2014.

CAMPBELL, J, R. (2016). 'Forward' in NIMKULRAT, N. KANE, F. & WALTON, K. (Eds.). (2016). *Crafting Textile in the Digital Age*. London: Bloomsbury. pp. XIX - XXIII.

CARDOSO, R. (2008). 'Craft Versus Design: Moving Beyond a Tired Dichotomy'. In: Adamson, G. (Ed.) *The Craft Reader*. Oxford: Berg. pp. 321–32.

DALGAARD, L. (2012). M*agical Materials to Weave: Blending Traditional & Innovative Yarns*. Translated by Ann Richards. Vermont: Trafalgar Square Books.

DEFRA UK. (2013). 'Prevention Is Better than Cure: The Role of Waste Prevention in Moving to a More Resource Efficient Economy'. T*he Waste Prevention Team DEFRA*. Available at: https://www.gov.uk/government/policies/reducing- and-managing-waste. Accessed: 03 January 2014.

DORMER, P. (1994). *The Art of the Maker: Skill and its Meaning in Art, Craft and Design*. London: Thames & Hudson.

DREYFUS, H, L. & DREYFUS, S, E. (1986). *Mind Over Machine: The Power of Human Intuition and Expertise in the Era of the Computer*. Oxford: Basil Blackwell.

FLETCHER, K. (2008). *Sustainable Fashion and Textiles: Design Journeys*. London: Earthscan.

FRAYLING, C. (2011). *On Craftsmanship: Towards a New Bauhaus.* London: Oberon Masters.

GROTH, C. (2017). 'Making Sense Through the Hands: Design and Craft Practice Analysed as Embodied Cognition. (PhD Thesis). Helsinki: Aalto University School of Arts, Design and Architecture.

GWILT, A. (2011). 'Make - Producing Sustainable Fashion'. In: GWILT, A. & RISSANEN, T. (Eds.). (2011). S*haping Sustainable Textiles: Changing the Way we Make and Use Clothes*. London: Earthscan. pp.59-73.

HARRIS, J. (2012). 'Digital Practice in Material Hands: How Craft and Computing Practices Are Advancing Digital Aesthetic and Conceptual Methods'. *Craft Research*. 3(1). pp. 91–112.

HEMMINGS, J. (2012). *Warp and Weft: Woven Textiles in Fashion, Art and Interiors.* London: A & C Black Publishers Ltd.

IRWIN, T. (2015). 'Transition Design: A Proposal for a New Area of Design Practice, Study, and Research'. Design and Culture. 7(2). pp. 229-246.

IRWIN, T. KOSSOFF, G. & TONKINWISE, C. (2015). Transition Design Provocation. Design Philosophy Papers. 13(1). pp. 3-11.

ISSEY MIYAKE. (c.2016). 'Making Things'. *Issey Miyake Inc.* Available at: https://www.isseymiyake.com/en/brands/isseymiyake/making. 05 January 2018.

KANE, F. (2013). 'Publication Review: Digital Visions in Fashion + Textiles: Made in Code, Sarah E. Braddock Clarke and Jane Harris 2012'. *Craft Research.* 4(2). pp. 289–292.

JAYARAMAN, S. & PARK, S. (2001). *Full-fashioned Garment with Sleeves Having Intelligence Capability* (Patent). Available at: http://www.google.com/patents/US6315009. Accessed: 07 January 2016.

JAYARAMAN, S. PARK, S. & RAJAMANICKAM, R. (2000). *Full-fashioned Weaving Process for Production of a Woven Garment with Intelligence Capability* (Patent). Available at: http://www.google.co.uk/patents/US6145551. Accessed: 07 January 2016.

LAWSON, B. (2006). *How Designers Think: The Design Process Demystified.* (4th Edition). Oxford: Elsevier Architectural Press.

LEE, Y. (2016). 'Seaming, Writing, and Making Strange: Between Material and Text'. *Studies in Material Thinking.* Vol. 14. Experience/Materiality/ Articulation'. Available at: https://materialthinking.org/papers/224. Accessed: 16 June 2016.

LEFFERTS, J. (2015). 'Gestalt Process'. *T:W:O by Jacqueline Lefferts*. Available at: http://www.jacquelinelefferts.com/#/gestaltprocess/. Accessed: 06 November 2018.

LEHMANN, A, S. (2012). 'Showing Making: On Visual Documentation and Creative Practice'. *The Journal of Modern Craft* . 5(1). pp.9–23.

LEHMANN, U. (2012). 'Making As Knowing: Epistemology and Technique in Craft'. *The Journal of Modern Craft*. 5(2), pp.149–164.

LEINIKKA, M. HOUTILAINEN, M, SEITAMAA-HAKKARINEN, P. GROTH, C. RANKANEN, M. & MÄKELÄ, M. (2016). 'Physiological Measurements of Drawing and Forming Activities'. In: *Proceedings of DRS2016: Design + Research + Society Future-Focused Thinking*. Vol.7 Embodied Making and Learning. pp. 2941-2958.

MALAFOURIS, L. (2013). *How Things Shape the Mind: A Theory of Material Engagement*. Cambridge: MIT Press.

MALAFOURIS, L. (2005). 'The Cognitive Basis of Material Engagement: Where Brain, Body and Culture Conflate'. In: DeMarrais, E. Gosden, C. & Renfrew, C. (Eds.). *Rethinking Materiality: The Engagement of Mind with the Material World*. Cambridge: McDonald Institute for Archaeological Research. pp. 53–61.

MANONIK. (2017). 'Manonik, Principles'. *Manonik*. Available at: http://www.manonik.com/about/. Accessed: 26 July 2018.

MARGETTS, M. (2018). 'The Growing is the Thing'. *Crafts Magazine*. No. 274. Sept/Oct 2018. pp. 36-44.

MCLAREN, A. (2015). 'Angharad McLaren Textiles'. Angharad McLaren. Available at: http://www.angharadmclaren.co.uk/#/angharad-mclaren-textiles/. Accessed: 29 July 2018.

MCCULLOUGH, M. (1997). 'Abstracting Craft: The Practiced Digital Hand' in Adamson, G. (Ed.) *The Craft Reader*. Oxford: Berg. pp. 310-316.

MCQUILLAN, H. (2010). 'Zero-Waste Pattern Cutting Process'. *Holly McQuillan*. Available at: http://hollymcquillan.com/download/. Accessed: 04 December 2013.

NIEDDERER, K & TOWNSEND, K. (2014). 'Designing Craft Research: Joining Emotion and Knowledge'. *Design Journal*. 17(3). pp.624–647.

NIMKULRAT, N. KANE, F. & WALTON, K. (Eds.) (2016). *Crafting Textile in the Digital Age*. London: Bloomsbury.

NIMKULRAT, N. (2012). 'Hands-on Intellect: Integrating Craft Practice into Design Research'. *International Journal of Design*. 6 (3).

NG, M, C, F. WANG, Z. HU, J. SZETO, Y, C. (2010). 'Shapeable Stretch Textiles via Compound Weaves for Seamless Woven Fashion'. *Textile Research Journal*. 80(12) pp.1191–1200.

NG, M. C. F. HU, J. SZETO, Y, C. & WANG, Z. (2007). 'Integrated Design of Seamless Fashion in Woven Textile with Multilayer"'. *Research Journal of Textile and Apparel.* 11(2). pp. 67–74.

O'CONNOR, E. (2007). 'Embodied Knowledge in Glassblowing: The Experience of Meaning and the Struggle Towards Proficiency'. *The Sociological Review*. 55(S1). pp.126–141.

OSBORNE, E, F. (2009). *Weaving Process for Production of a Full Fashioned Woven Stretch Garment with Load Carriage Capability* (Patent). Available at: https://bit.ly/2mKyXdI. Accessed: 07 January 2016.

PALLASMAA, J. (2009). *The Thinking Hand*. Chichester: John Wiley & Sons.

PARRY-WILLIAMS, T. (2015). 'Made-by-hand: [Re]valuing Traditional (Japanese) Textile Practices for Contemporary Design.' *Craft Research*. 6 (2). pp. 165-186.

PARRY-WILLIAMS, T. (2007). 'Craft: Industry Interface – A dialogue between hand, heart and machine (an Anglo-Japanese collaboration)'. In: Follett, G. & Valentine, L. (Ed.). *New Craft – Future Voices Conference Proceedings*. Dundee: Duncans of Jordanstone College of Art & Design. pp. 73-85.

PEDGLEY, O. (2007). 'Capturing and Analysing Own Design Activity'. *Design Studies*. 28(5). pp.463–483.

PHILPOTT, R. (2012). 'Crafting Innovation: The Intersection of Craft and Technology in the Production of Contemporary Textiles'. *Craft Research.* 3(1). pp. 53–74.

PIPER, A. & TOWNSEND, K. (2015). 'Crafting the Composite Garment: The Role of Hand Weaving in Digital Creation'. *Journal of Textile Design Research and Practice*. 3(1-2). pp.3-26. Available at: https://www.tandfonline.com/doi/abs/10.1080/20511787.2015.1127037. Accessed: 10 November 2018.

POLANYI, M. (1966). *The Tacit Dimension*. (Reissue Edition). London: University of Chicago Press.

PYE, D. (1968). *The Nature & Art of Workmanship.* Cambridge: Cambridge University Press.

RATHNAYAKE, A. PIPER, A. & TOWNSEND, K. (2012). 'Woven Garment with Integrated LED Yarn Technology'. *Future Textiles Exhibition*. London: Palace of Westminster.

REASON, P. & BRADBURY, H. (Eds.). (2001). *Handbook of Action Research (Concise Paperback Edition)*. London: SAGE.

RICHARDS, A. (2012). *Weaving Textiles That Shape Themselves*. Ramsbury: The Crowood Press Ltd.

RISSANEN, T. & MCQUILLAN, H. (2016). *Zero Waste Fashion Design*. London: Bloomsbury.

RISSANEN, T. (2013). 'Zero-Waste Fashion Design: A Study at the Intersection of Cloth, Fashion Design and Pattern Cutting'. (PhD Thesis). Sydney: University of Technology Sydney.

SCALON, J. (2004). 'Seamless: Issey Miyake Saw the Future of Fashion'. *Wired*. Vol. 12. 4. P.162-167. Available at: http://www.wired.com/wired/archive/12.04/miyake_pr.html. Accessed: 11 November 2013.

SCHÖN, D, A. (1991). *The Reflective Practitioner: How Professionals Think in Action*. London: Ashgate.

SINGH SAWHNEY, A, P. (1972). 'Apparel Weaving – A New Concept'. *Textile Industries*. Dec 1972. pp.50-56.

SMITH, T. (2014). *Bauhaus Weaving Theory: From Feminine Craft to Mode of Design*. London. University of Minnesota Press.

TAYLOR, J. (2015). 'The Technical Designer: A New Craft Approach for Creating Seamless Knitwear. (PhD Thesis). Nottingham: Nottingham Trent University.

TAYLOR, J. & TOWNSEND, K. (2014). 'Reprogramming the Hand: Bridging the Craft Skills Gap in 3D/digital Fashion Knitwear Design'. *Craft Research*. 5(2). pp.155–174.

THOMAS, L. (2009). 'Woven Structures and Their Impact in the Function and Performance of Smart Clothing'. In: MCCANN, J. & BRYSON, D. (Eds.). (2009) S*mart Clothes and Wearable Technology*. Cambridge: Woodhead Publishing in Textiles. pp.131–155.

TOWNSEND, K. (2016). 'Closely Held Secrets: Embodied Knowledge in Digitally Crafter Textiles'. In: NIMKULRAT, N. KANE, F. & WALTON, K. (Eds.). (2016). *Crafting Textile in the Digital Age*. London: Bloomsbury. pp. 189-206.

TRULLEN, J. & TORBERT, B. (2013). 'First-, Second-, and Third-Person Research in Practice'. *The Systems Thinker*. Available at: https://thesystemsthinker.com/first-second-and-third-person-research-in-practice/. Accessed: 26 May 2018.

VALENTINE, S. (2011). 'Craft as a Form of Mindful Inquiry'. *The Design Journal*. 14(3). pp. 283–306.

VITRA DESIGN MUSEUM. (2001). *A-POC Making: Issey Miyake and Dai Fujiwara* (Exhibition Catalogue). Berlin: Vitra Design Museum.

WANG, X. (2011). 'A Study on Silk Full-Fashioned Weaving for Women's Wear'. *Advanced Materials Research* .175. pp.1035–1039.

WANG, X. NG, M, C, F. HU, J. & SZETO, Y, C. (2009). 'Shapeable Stretch Textiles via Simple Weaves for Seamless Woven Fashion'. *Textile Research Journal*. 79(18). pp.1715–1724.

WATKINS, S, M. & DUNNE, L, E. (2015). *Functional Clothing Design: From Sportswear to Spacesuits*. London: Bloomsbury.

WRAP. (2017). 'Sustainable Clothing: A Practical Guide to Enhancing Clothing Durability and Quality'. *WRAP.* Available at: http://www.wrap.org.uk/sites/ les/wrap/ Sustainable%20Clothing%20G uide%202017.pdf. Accessed: 20 September 2017.

2 Knowing Through Making:

The Role of Embodied Knowledge in Hand and Digital Design and Production

2 Knowing Through Making:

The Role of Embodied Knowledge in Hand and Digital Design and Production

2.1 Knowing Through Making Aim

To investigate the role that embodied weaving knowledge plays in informing textile design innovation by recording and analysing the iteration between, and transition from, analogue to digital production, through reflective practice.

2.2 Knowing Through Making: Chapter Overview

This chapter explores the relationship between theoretical and practical knowledge of weaving. By drawing parallels between the practice of hand weaving and computer aided design (CAD) for weaving (Section 2.8), the chapter considers how the knowledge and skill of hands-on making can assist a designer to make the transition from hand to digital production. Furthermore, by analysing and reflecting upon my own weaving practice (Section 2.9), it identifies a reciprocal relationship of working iteratively between hand and digital weaving platforms to generate new ideas and opportunities for zero waste and sustainable textile and garment production.

Central to this discussion is the concept of embodied (experiential or tacit) knowledge (intuitively embodied in the maker through direct physical engagement with materials and processes) (see Lehmann, U 2012 and Pallasmaa 2009) and the apparent difficulties craftspeople have when articulating and communicating such knowledge (see Malafouris 2013 for Material Engagement Theory). This chapter lays the foundations for the Transitional Design Methodology (Chapter 3) and determines the format of this thesis (Section 2.7.1).

2.3 Material Relationships: Knowledge Acquisition and Material Engagement

This section discusses the nature of and the relationship between taught and practical (or hands-on) knowledge in craft practice. Using Dreyfus and Dreyfus' stages of "Knowledge Acquisition" (1986) it outlines how knowledge and skills are acquired and refined through application and experience. It goes on to consider how, in the making/craft process, knowledge is derived through direct engagement with materials and process, before exploring how knowledge of hand weaving can aid the transition to digital design and production techniques such as digital Jacquard weaving.

2.3.1 Knowledge Acquisition: Theory, Experience & Skill

we know more than we can tell (Polanyi 1966: 4)

Two types of knowledge converge in skilful practice: technical taught principles, articulated verbally or textually, (i.e. explicit knowledge) of a craft discipline, and knowledge derived through engagement with materials and processes (e.g. intuition, understanding, 'knowing'), referred to as embodied (or experiential) knowledge (Lehmann, U 2012; Polanyi 1966). This experiential (or non-propositional) knowledge can be impossible to articulate and therefore remains "largely tacit" (Niedderer & Townsend 2014: 633).

Referring to the relationship between explicit and tacit knowledge Polanyi states, "a true knowledge of a theory can be established only after it has been interiorized and extensively used to interpret experience." (1966: 21). The teaching of a design or craft practice, therefore, often combines verbal description and demonstration, with the student (or apprentice) observing the "skilful performance" (Ibid: 29) of an expert – mentally capturing their physical movements and explanations, whilst the internal intellectual action of the expert's mind remains elusive to the observer.

Dreyfus & Dreyfus (1986: 16-51) breakdown the indwelling and interiorization of learned knowledge, through experience, into five stages of "Knowledge Acquisition": Novice, Advanced Beginner, Competence, Proficiency and Expertise. These five stages can be observed in the learning of any practical skill, including in the process of learning to weave.

The Novice, who re-enacts taught rules, progresses to the stage of Advanced Beginner as rules are put into context and made meaningful through experience. As the learner advances to the level of Competence she/he no longer simply follows prescribed rules but sets goals, becoming emotionally invested and taking responsibility for the decisions they have made. This emotional investment increases with Proficiency, past experience informs new experience, with important elements brought to the fore and the less important residing in the background. Responses, actions and decisions become intuitive, drawing on and analysed through past experience and rules. Decision-making becomes increasingly intuitive, as the Expert knows what to do through "practiced understanding" (Ibid: 30) and works spontaneously in a process of unconscious action. This progression from Novice to Expert blurs the boundaries between learned and experiential knowledge, as intuition transcends defined explicit rules.

Through her ethnographic research into shoe making, Braithwaite connects a maker's skill level (or competence) with his/her ability to describe feelings and actions undertaken as part of the creative process, stating:

> As the shoe designers had become accustomed to the rhythmic actions of the making process they were less able to describe these feelings of material transformation.
>
> (2017: 93)

Conversely, the novice practitioner remains able to describe, record and reflect upon individual aspects of the process. This changing ability to verbalise (or articulate) feelings and actions reflects the shift from re-enacting taught principles to intuitively acting and reacting using embodied knowledge.

In weaving, this intuitive action informed by past experience is evident not only in the physical process/act but also in the preparatory activities of making and winding the warp and threading the loom (Figure 2.1) (Section 2.8.1); individual actions merge and become part of a wider process. Actions, such as separating and preparing the weft yarns to thread through the heddles, are taken instinctively to form a continuous, repetitive and rhythmic process (Journal Excerpt 2.1).

> The constitutive rules of a craft are only learned by actually doing the activity. Indeed, they are the activity. **You cannot understand it or know it until you can do it.**
>
> (Dormer 1994: 42)

Figure 2.1: Material Engagement During Warp Winding (2016)
Photograph by Neil Piper

2.3.2 Material Engagement: 'Knowing' Through Making

The acquisition of skill and skilful making involves mind, body and material; it is "an embodied tactile journey" (Pallasmaa 2009: 109), where 'knowing' is inextricably linked to the act of making. In craft practice, technical knowledge of materials and processes is combined with haptic experience "to enable successful interpretation, manipulation and judgements required for working with any particular material or process." (Niedderer & Townsend 2014: 636).

Schön considers design to be "a conversation with the materials of a situation" (1991: 78), where knowledge and understanding of materials is derived and embodied through interaction and use. The designer's response to materials links to their tacit knowledge of how materials they have used before will perform. However, 'new' materials have unknown qualities that can only be understood, then 'managed', through direct first hand engagement. Therefore, practice-led research requires a combination of experimentation, open-mindedness as well as embodied knowledge in order to understand the potential of new materials, tools and technologies. In this research, experimentation and engagement with materials takes place across multiple modes of production (hand, digital and hybrid) with the intention of exploring and exploiting the potential of materials and processes, as well as traditional looms and advanced weaving technologies.

> Its just happens that you begin to think, "this is catching my interest" and you take a thread and another and it looks promising in some way and you think something may develop from this... but I do think a kind of playfulness is necessary, and just being led by the material.
>
> (Albers 1985 in Margetts 2018: 36)

Making frequently involves the use of a tool(s) to facilitate or assist in the manipulation or shaping of materials. Using the tool, the maker is able to experience the materials and form the object, transferring and externalising ideas from mind, via body and tool, to the material world (Malafouris 2013). The skilful use of such tools has to be learned; the maker has to negotiate and learn, through experience, how to handle and control the tool, and in doing so develops a relationship with and comes to 'know' their materials.

> For an experienced ceramicist, the density of a bit of clay immediately gives an idea of its possible uses, together with an either positive or negative background feeling simultaneously. If the clay is too hard, it is not good because it cannot easily be handled and needs to be soaked. If the clay is too wet, it is also not good and it needs to be dried until workable. A perfectly smooth and dense bit of clay gives a good forecast for any project, and is therefore experienced with positive emotions.
>
> (Groth 2017: 147)

Groth suggests that sensory material engagement evokes emotion in the maker which informs risk assessment, decision-making and problem-solving (Ibid: 57). The maker interprets the feel of the material positively or negatively based on prior knowledge and experience, and adjusts his/her actions in response to the perceptual feedback. Groth therefore establishes a connection between haptic (material) engagement, emotion, skilful making and craft knowledge.

In weaving there is a dialogue (or 'conversation') between the body, the loom and the yarns. Whilst aspects of the process are pre-planned - the threading, the warp yarns and structures – the experienced weaver (via the loom) 'feels', responds to and manipulates the yarns and weave structures to form a unique cloth. Each fabric tells the 'story' of its construction, evident in the tension, density and (in)consistency of the cloth – reflecting the weavers conscious and intuitive responses to the materials and process (Journal Excerpt 2.2).

2.4 Digital Craft: Debates and Perceptions

Pye (1968) makes a distinction between two types of workmanship – the "workmanship of risk" and the "workmanship of certainty". The workmanship of risk is aligned to craftsmanship and skilled making that requires hands-on engagement and truth to materials – a process that yields individuality and quality. The workmanship of certainty is deemed inferior, often associated with mass production, standardisation and accuracy: a machine-led process where "the result is predetermined and unalterable once mass production begins" (Ibid: 6). Similarly, McCullough declares:

> Craft is the application of personal knowledge to the giving of form. It is the condition in which inherent qualities and economies of the media are encouraged to shape both process and products. It is not about standardized products, however.
>
> (1997: 312)

However, in associating craft with quality, Pye acknowledges that the handmade does not always result in skilfully made objects; qualifying the relationship between handmade and quality by stating that: "The workmanship of risk has no exclusive prerogative of quality." (1968: 7). Indeed, Cardoso refers to industry as being "increasingly able to provide high-quality and even custom-made production" (2008: 330).

Whilst certainty is perceived negatively by some (including Pye and McCullough), others recognise that by combining hand and machine processes "an element of unpredictability" can be retained (Philpott 2012: 67). These hybrid forms of production allow the practitioner to balance the creativity and individuality of hand-crafting with the precision and predictability of automated production, to produce innovative high-quality outcomes that challenge traditional perceptions of craft.

In discussing the nature of craftsmanship, in relation to hand and mechanical (or mechanised) processes, Pye distinguishes between types of machinery:

> Now we shall have to define 'machine' so as to exclude a hand-loom, a brace and bit, a wheel-brace, a potter's wheel and the other machines and tools which belong to what is generally accepted as hand-work.
>
> (1968: 9)

For Pallasmaa, tools are seen to guide action and thought and are, therefore, not "equal and exchangeable" (2009: 50). Whereas the use of a pencil results in haptic sensory engagement, "Computer drawings are devices for a bodiless observer." (Ibid: 98), it is a "purely retinal journey" (Ibid: 99). Using the term "computer-generate" he suggests an automated process with the user an outside observer rather than a haptically-engaged maker, resulting in a loss of skill, as reiterated in the final observation in the 'Art of the Maker':

> If the loss continues, it will be not only as a consequence of computerization, but of our response to it.
>
> (Dormer 1994: 104).

However, Dormer's statement does not rule out the use of computers in craft practice but suggests that the way technology is used is the key to retaining craft knowledge. Likewise, Frayling argues "[…] it is more a question of the ways in which the machines are used, and of the context of their use." (2011: 76), where machines assist the handmade, by facilitating small batch production using "new kinds of tools" (Ibid: 82). Cardoso echoes this view, seeing the digital as an opportunity to transform craft, whilst wrestling with the idea of digital manipulation as craftsmanship due to the lack of "bodily presence" (Cardoso 2008: 329). He equates computer use to the craft of glassblowing; there is no direct contact with the item being made but "form is directly determined (i.e.) informed by the knowledge and practice of a maker" (2008: 329). Similarly, Jacquard power weaving requires prior knowledge of structural characteristics and the interlacement of warp and weft yarns. Derived through hand weaving, this knowledge of woven construction is applied, tested and expanded through digital production and may, subsequently, be reapplied to inform/advance hand woven construction; an approach that forms the basis of the Transitional Design Methodology employed in this research (Section 3.3).

More recently, Campbell has discussed the evolution in the use of digital tools in craft practice, identifying a shift from using digital tools to "intentionally show a digital effect" or to "mimic a traditional effect or technique" towards a more integrated understanding and use of new and emerging technologies (Campbell 2016: XIX). He connects this with a change in the way we think about materials, stating:

> In this way of thinking, all technological innovations addressed through craft practice have the iterative role of presenting new ways of making while also leading to the knowledge required to advance the technology.
>
> (Ibid)

Digital technologies are no longer considered to be tools that assist designers but instead they are changing design practice (Campbell 2016; Harris 2012). They offer new creative potential and aesthetic opportunities, and enable new ways of working, thinking and communicating craft knowledge, resulting in the emergence of a new form of craft practice – digital craft.

2.4.1 Digital Potential: A Tool and Facilitator

Adopting approaches from outside your own field is a recognised strategy for problem-solving, advancing practice and inspiring innovation by challenging established tradition and paradigms (Lehmann, U 2012; Abbott 2004). Digital technology has the potential to provide precision, reproducibility, rapid and virtual prototyping ability. In craft research, practitioners often advance processes and outcomes by applying craft-based methodologies to their use of digital tools – pushing the boundaries of materials and processes for innovation (see Paine 2016; Taylor 2015; Goldsworthy 2012).

The significance of this integration of digital technologies and (hand) craftsmanship is reflected in Nimkulrat, Kane and Watson's recent publication 'Crafting Textiles in the Digital Age' (2016), Johnston's 'Digital Handmade: Craftsmanship and the New Industrial Revolution' (2015) and Braddock Clarke and Harris' 'Digital Visions for Fashion and Textiles' (2012). These publications collate the work of a vast array of 'digital craft' practitioners who combine craft knowledge and skill, with digital tools by developing "creative partnerships with digital technology" (Kane 2013: 290).

> To achieve innovation which covers both design and technology, we have to update our existing knowledge base. Nowadays, textile innovation demands interdisciplinary abilities, because it often means the development of a new concept, a new method, and a new product, rather than a successful appearance. It is both an opportunity and challenge.
>
> (Jiang 2009: 46)

A growing body of textile practice focuses on how digital technologies can inform new design and production strategies that challenge and extend the field (Nimkulrat et al. Eds. 2016; Braddock Clarke & Harris 2012), resulting in "new kinds of practice, expanding the remit of the maker into unexpected professional territories." (Harris 2012: 97). Through the integration of digital weaving technologies with established ZWPC methods and sustainable design strategies, this research aims to expand the field of sustainable garment design by assimilating textile and fashion design and construction to produce woven garments that eliminate cutting waste and minimise material production.

2.5 Integrating Traditional Craft and Advanced Technologies: Linear Methodologies

This section considers a selection of contemporary and longstanding methodologies applied in textile design research (Sections 2.5.1 and 2.5.2) and commercial textile production (Sections 2.5.3 to 2.5.6) that integrate traditional craft and advanced technologies towards innovation in fashion and interior contexts. It critiques the methodologies and considers the limitations of a linear approach to the integration of analogue and digital practices.

2.5.1 Hand Weaving for Mechanised Production

Bauhaus weaving theory places hand experimentation at the heart of innovative practice. The School's weaving methodologies were rooted in craft practice and "handwork" - using hand weaving as the basis for developing woven textiles for industry (Smith 2014).

> It is only by working on a handloom that one has enough room to play, to develop an idea from one experiment to the next, until there is enough clarity and specification about the model for it to be handed over to industry for mechanical production.
>
> (Stolzl 1926 in Smith 2014: 64)

Stolzl, like her Bauhaus contemporary Anni Albers, highlighted the limitations of mechanised production and the barrier it places between designer, materials and process. In situating hand experimentation at the centre of practice, Albers and Stolzl's philosophy emphasises the "role of material" (Margetts 2018: 36) and the importance of process engagement in exploiting the technical possibilities of mechanised production, establishing its parameters and improving the relationship between "human subjects and woven things." (Smith 2014: 48). Albers and her contemporaries did much to elevate the craft and status of hand weaving, and it is partly because of this that it remains at the forefront of a linear process of design development and production that limits the possibilities of innovation through intervention and a reciprocal exchange of knowledge.

2.5.2 Craft and Advanced Technologies in Practice: Contemporary Textile Design Research

Rachel Philpott uses the practical hands-on experience of folding materials to allow her to "acquire practical understanding" of folding diagrams and 3D folded forms, to conceptualise and translate them into CAM/CAD software (2012: 61). For her, the embodied knowledge derived from a haptic relationship with materials and processes is essential in the transition from hand to digital construction. In making the transition from hand to digital, Philpott acknowledges a changing relationship between the maker and the material – a physical distance – whilst the technology facilitates accuracy and complexity. Digital processes are referred to as "disembodied" (Philpott 2012: 54), where:

> The introduction of automated machine production and CAD/CAM technology alter the relationship between maker and material, reducing or removing the direct physical link between the practitioner and the processes and materials of their practice.
>
> (Ibid: 56)

Philpott's methodology demonstrates an approach to digital practice where the embodied knowledge of hand construction enables digital programming to produce textile structures that would not be possible using hand construction alone. She emphasises the application of digital and machine technologies as tools of efficiency and reproducibility, as well as a facilitator of advanced construction. The practices are described as being "entwined" (Ibid: 69):

:

> This has been illustrated by the journey of my practice from physical origami folding, to computer generation and representation of origami folding patterns, translation of these results through the process of laser-cutting and hand construction techniques before returning to a different iteration of the physical folding.
>
> (Ibid)

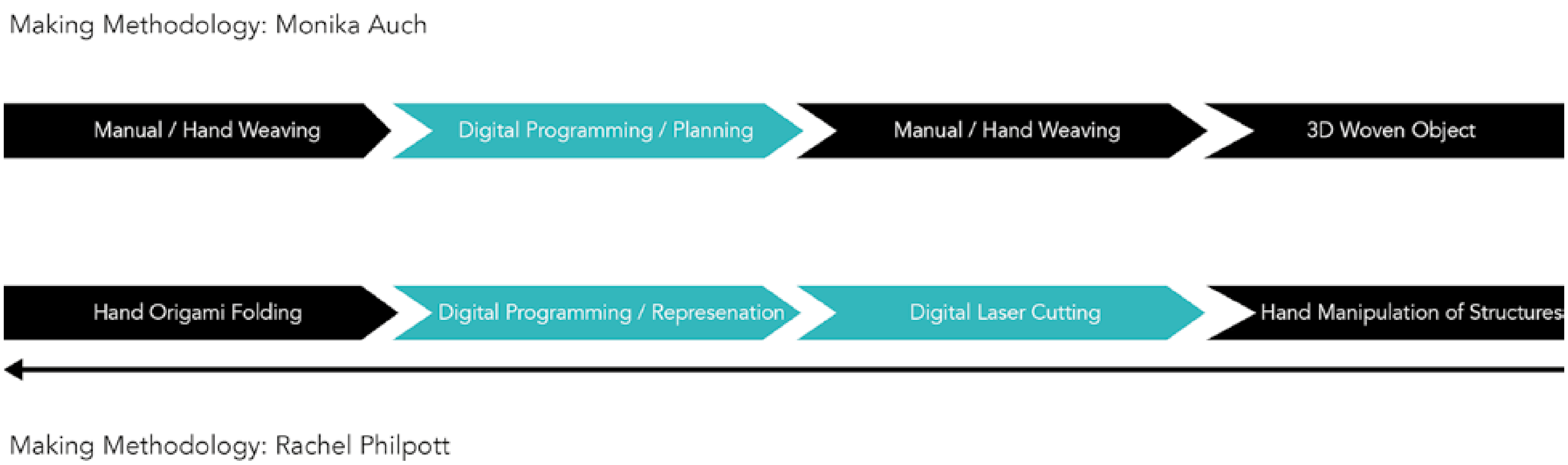


Figure 2.2: Making Methodologies: Monika Auch and Rachel Philpott (2017)
Illustration by Anna Piper

Monika Auch is a visual artist with a background in medicine. She works with "slow traditional techniques" including weaving to produce "fibre sculptures" (Auch c.2017). Through her practice-led research she explores the effects of hands-on making on the brain and wellbeing (Ibid).

Auch works on a computer-controlled loom to produce 3D woven objects, that combine the "intelligence of the hand" and the "sensibility of materials" (Auch 2016: 61). Like McCullough (1998), she views CAD/CAM technologies as a tool to be mastered where a cognitive relationship develops to facilitate skilful use of these technologies (Section 2.8.4). In contrast to the established view of technologies providing efficiency, in relation to the sampling processes she states:

> CAD/CAM machines do not speed up the process but, quite contrarily, can slow it down because of the increasing possibilities in designing and manufacturing.
>
> (Ibid: 66)

However, she adopts a methodology of manual weaving followed by computer-based planning, before returning to the manual weaving process – a process where hand production facilitates the conceptualisation of designs.

The loom's shafts are programmed to lift and lower through digital programming, but in weaving the practitioner maintains haptic engagement with materials and process by manually inserting the weft yarns (as in traditional weaving). This type of weaving can be considered hybrid, sitting between traditional hand weaving and fully mechanised digital production, where the weaver is unable to alter the pre-programmed design when production begins.

Philpott and Auch exhibit two successful but fundamentally different integrations of craft and advanced technologies in textile practice (illustrated in Figure 2.2). Philpott combines independent hand and digital processes to make a single object/textile, whilst Auch employs a computer-controlled loom that blurs the boundaries between hand and digital production. Despite these fundamental differences, these two designers represent an integrated but staged linear transition, moving from hand to digital and back again and producing innovative textiles that combine the two approaches.

Figure 2.3: The Iterative Relationship Between Garment Prototypes and Modes of Productiion (2018)
Illustration by Anna Piper

Whereas these approaches result in a single design or object, in this research the design ideas, findings and processes developed and derived through sampling and garment construction, on the hand, digital and/or hybrid looms, informs multiple concurrent designs and subsequent designs. As such, hand construction can inspire digital and/ or hybrid designs, but equally digital and hybrid construction can inspire hand woven designs (Figure 2.3). Processes become integrated, not in their shared use within a single design, but in their shared application across a series of designs.

2.5.3 Craft and Advanced Technologies in Practice: Contemporary Commercial Japanese Textiles

The Japanese fashion and textile industries are renowned for their innovative approaches and design outcomes, whilst still reflecting a traditional ethos and craft-based methodologies. Designers including Junichi Arai, Reiko Sudo (founders of the Nuno Corporation) and Issey Miyake are extolled as pioneers in their disciplines (the former in textiles and the latter in both textiles and fashion) (see Ideas on Design 2013 and English 2011).

This section discusses the development of Miyake's '3D Steam Stretch' (2014) and 'Baked Stretch' (2016) textiles, and his Womenswear Creative Director Yoshiyuki Miyamae's combination of hand and digital processes. This is followed by analysis of collaborative research by Tim Parry-Williams (2015; 2007) into the integration of craft weaving and industrial processes. Both exhibit an approach to textile development and production that use traditional craft processes as a platform for innovation in a commercial context.

2.5.4 Craft and Advanced Technologies in Practice: Issey Miyake

Issey Miyake '3D Steam Stretch': in 2015 Issey Miyake introduced their '3D Steam Stretch' technology into their Spring/Summer womenswear collection. '3D Steam Stretch' advances the brand's trademark pleated textiles and garments; applying steam to polyester and cotton woven structures to generate 3D form and folding into the fabric. It combines common fibres with complex computer programming to calculate precise textile compositions (Howarth 2014). Subsequently Issey Miyake launched their 'Baked Stretch' line in 2016. 'Baked Stretch' involves the application of a glue-based substance to the surface of a textile; when exposed to heat the fabric is manipulated creating undulations in the cloth (Howarth 2016). Although achieved through collaborative development, Yoshiyuki Miyamae is credited as being the initiator of the processes. Being of the generation where computer technology is widely available Miyamae states:

> I'm not too conscious that we have to put importance onto the usage of digital software as such. For us, anything available nowadays like a personal computer or weaving machine are part of tools that bring ideas into reality.
>
> (Howarth 2014)

In discussing the development of '3D Steam Stretch' he describes a process using paper prototypes and experimentation as a means of understanding and conceptualising the fabric designs; an approach that balances manual and digital processes for the purpose of advanced textile innovation.

> We created paper prototypes of the shapes. We tried many patterns including squares and triangles. We usually tend to work like that and to make one paper prototype takes about a day to make it work. The way I came to this point is through endless research and experimenting at the paper stage and gradually translating it into fabric.
>
> (Howarth 2014)

However, promotion of the concepts through digital visualisation (see Issey Miyake c.2016), give the impression of a product solely attributed to advanced digital technologies, rather than a product that has evolved from haptic knowledge and manipulation of materials.

The interviews and articles published relating to innovations within Issey Miyake only provide a limited insight into a highly creative and advanced process of technical textile and fashion development. However, it remains an informative example of the central role hands-on making (and craft knowledge) plays in contemporary commercial textile development, and bears a striking resemblance to Philpott's craft research methodology (Section 2.5.2).

2.5.5 Craft and Advanced Technologies in Practice: Tim Parry-Williams

Tim Parry-Williams' research into materials, yarn properties and woven structures, is informed by Japanese textile practices and sensibilities. Having studied at Okinawa

Prefectural University of the Arts (Japan), Parry-Williams has written extensively about Japanese textile traditions and is a visiting lecturer at a number of Japan's educational institutions (Bath Spa University 2017). His papers 'Craft: Industry Interface – a dialogue between hand, heart and machines (an Anglo-Japanese collaboration)' (2007) and 'Made-by-hand: [Re]valuing Traditional (Japanese) Textile Practices for Contemporary Design' (2015) examine the dialogue between craft practice and industry processes, through collaboration with the Japanese woven textile industry.

Parry-Williams discusses a collaborative methodology of "sampling original ideas by hand; and trials […], resampling and selecting, toward producing fashion textiles at an industrial level" (Parry-Williams 2007: 74), an approach that echoes that of the Bauhaus weavers (Section 2.5.1). He describes an "extended intervention" (Ibid: 81) whereby craft knowledge can be applied in commercial weaving, through the presentation of samples for "discussion and debate and mutual knowledge and understandings shared" (Ibid: 78). More specifically he refers to hand weaving influencing direct intervention in the industrial processes – changing the gears of the power loom to take "direct control of the take-up" (Ibid: 80) to echo the hand weavers control of density through variations in beating the weft into place.

In his 2015 paper, he also describes his research working with fibres and yarns rooted in Japanese textile traditions and ways of life that have declined in their usage due to their incompatibility with industrial production.

> Despite significant quality achieved through expert skill, the nature of such yarns (in their broad inconsistencies) makes them difficult to work with outside of their traditional context.
>
> (Parry-Williams 2015: 176)

Fibres native to Japan, including hemp and ramie, have been superseded by silk, cotton and wool as they are easier to produce and process (Ibid: 172). Combining these 'traditional' bast-fibres with more manageable fibres such as silk, Parry-Williams has developed a series of hand woven textiles, that have been trialled with industrial weaving equipment; achieved through "careful manipulation of machine parts and technical patience" (Ibid: 176).

In opposition to the traditional view of technology, Parry-Williams asserts that a collaborative approach to combining hand and digital processes is a form of craftsmanship (Parry-Williams 2007: 78). Woven outcomes are crafted – encompassing craft skills and embodied knowledge of materials, structures and finishes expressed and formed using digital tools.

Parry-Williams views his ‘Anglo-Japanese collaboration’, in particular, as utilising a cyclical methodology, with the outcomes being “neither craft in its traditional form, nor pure industrial work.” (Ibid: 83). For him, the process integrates craft knowledge with the industrial system, through an exchange of ideas to facilitate the production of original textiles. Parry-Williams states: “Hand woven samples become models and vehicles of concept subsequently informing an industrial system” (Ibid: 73) thus highlighting a process where hand production precedes power loom production in a more traditional linear fashion - like the methodologies developed at the Bauhaus (Section 2.5.1). There is no suggestion of a converse ‘reciprocal relationship’ (Section 2.9.2), whereby industrial production facilitates the conceptualisation of hand outcomes. Furthermore, digital technologies are identified as enabling efficient exploration and diversification of design ideas, in a process where craft knowledge is applied to automated production and textile traditions can be sustained through “modified use of established systems” (Parry-Williams 2015: 166).

2.5.6 Integrating Traditional Craft and Technologies: Developing a Transitional Methodology

> Digital fabrication as a creative method of making is generally perceived to sit more comfortably with mass manufacturing than the realm of craft. An expectation of the craft process is the relationship between hand, eye and material, naturally preceding the use of computing [...]
>
> (Harris. 2012: 93)

Neither Parry-Williams nor Miyamae explicitly acknowledge the influence of advanced technologies on innovation in hand construction. Both of their approaches exhibit the continued application of principally linear design methodologies that result in innovation and commercially successful concepts and outcomes. Moreover, their work implies that the adoption of a more integrated, transitional use of craft and advanced technologies has the potential to supply designers and researchers with greater conceptual and experimental capacity to advance both traditional and advanced practices.

Building on these and other holistic approaches to hand/digital craft and intervention (see Taylor 2015; Philpott 2011; Townsend 2004) this research proposes that a more iterative integration of hand and digital processes is necessary for creating design solutions that explore and reflect the full potential of hand and digital expertise. Therefore, this research advocates a move away from a linear approach where hand precedes digital as a means of design conceptualisation, by adopting an innovative alternative 'transitional methodology' (Chapter 3) of working between traditional and advanced technologies to challenge the constraints of the two modes of production whilst capitalising on their advantages and qualities.

2.6 Practice-led Research

Academic research has traditionally been rooted in scientific methods (Doloughan 2002), and the requirement of "making everything explicit, by revealing the methods of one's logic and justifying one's conclusions" (Frayling 1993: 3), through the production of written texts. Scientific research has been seen to be 'separate' from the scientist/researcher (Ibid) – systematic and objective in his/her analysis of quantitative data and formation of conclusions, in order to uncover an "ultimate truth" (Barrett 2007: 1).

> He takes a problem, makes tentative conjectures regarding the answer to it and keeps revisiting the answer in light of neat, well-ordered experiments, which must be repeatable or replicable.
>
> (Frayling 1993: 3)

Increasing emphasis is being placed on multidisciplinary research methods (in craft and design research, and in fashion and textile design (Nimkulrat, Raebild & Piper 2018: 4)) to acquire new types of knowledge, acknowledging "the limits of traditional ways of presenting the world" (Barrett 2007: 1) and recognising that:

> The informed, intimate perspective of the reflective practitioner leads to a greater degree of insight only possible from experiential, 'tacit' knowledge.
>
> (Gray & Malins 1995: 3)

As a result, value is being placed on research and acquisition of knowledge through hands-on making and experimentation – practice-led research. Gray & Malins describe practice-led research as "involving practitioners researching through action and reflecting on action" with the researcher and the research context "central to the inquiry" (1995: 3). It responds to or is led by a designer or craftsperson's studio practice, whereby creative practice is the primary research method (De Freitas 2002).

Practice-led research is not simply a process of capturing the practitioner's activities or experiments; it is a critical process that involves the "active documentation" of practice, for the purpose of critical analysis and interpretation (Ibid). Such an approach is necessary for moving a discipline or practice forward.

In practice-led research the 'problem' can emerge over time, and the benefits of the research may also emerge as the research progresses (Haseman & Mafe 2009). This is not to say that practice-led research is without direction or purpose, it is an approach (or combination of approaches) that "integrate the tacit knowledge and creative practices of design within a clearly articulated set of research priorities." (Press & Cooper 2003: 127).

However, this relatively new approach to research (Gray and Malins 1995)[1] has been criticised for both the quality of communication of research outcomes (De Freitas 2002), and the level of objectivity due to the centrality of the practitioner in the research and the absence of scientific criteria to quantify research findings. Gray and Malins, amongst others, argue that:

---

[1] In their 1995 paper 'Appropriate Research Methodologies for Artists, Designers & Craftspersons: Research as a Learning Process' Gray & Malins refer to a "steady increase in the number of registrations for higher degrees in the area of the Visual Arts." over the previous decade. They highlight a limited number of formal research projects in the area of craft utilising practice-led methodologies.

> This reveals a fundamental misunderstanding […] The criteria with which to judge the results of any research must take into consideration the original research question, its aims and objectives, and be negotiated through critical self-assessment dialogue with peers (acknowledging multiple perspectives), and taking into account the evolutionary nature of research.
>
> (1995: 4)

Frayling (1993) and Barrett (2007) draw attention to the appropriateness (or suitability) of an approach for a particular study/type of research. Barrett states:

> [...] knowledge is relational and that different models of inquiry will yield different forms of knowledge.
>
> (2007:1)

Frayling notes that there are similarities in "doing" science, design and making art – they are all practiced, and involve the hand and the brain (1993: 4); as such creativity and objectivity, science and subjectivity are not mutually exclusive (Doloughan 2002).

> Practice-based enquiry has a role to play in extending new frontiers of research.
>
> (Ibid: 58)

Practice-led research involves the adoption of multiple research methods that frequently draw from other fields (Haseman & Mafe 2009); it is an "exploratory tool" and a means of "validating existing modes of practice or identifying new directions" (De Freitas 2002) which can result in the development of new methodologies and ideologies, as well as technical findings/outcomes. This type of research is as much about knowledge derived through process as it is about the physical outcome (or product) (Barrett 2007).

As such, researchers/practitioners in the fields of textiles and fashion design are utilising practice-based research to find new methods for fashion design and construction (see Lindqvist 2015; Townsend 2004) to develop more sustainable approaches to fashion and textile production (examples include Rissanen 2013 and Goldsworthy 2012), as well as to explore opportunities for integrating traditional and advanced digital technologies for textile innovation (such as Taylor 2015 and Philpott 2011).

2.7 Capturing & Communicating Craft Knowledge

> Verbal description, however detailed, can hardly capture the phenomenological perturbations of real activity.
>
> (Malafouris 2005: 59)

As a researcher/practitioner, I experience the frustration of attempting to articulate my process and knowledge in textual form. The growing body of practice-led research has highlighted the complexities of communicating craft knowledge (particularly experiential knowledge) within the constraints of the traditional academic written format (see Niedderer & Imani 2008). Barrett suggests, “there is a need for new ways of representing ideas and illuminating the world and domains for knowledge.” (2007).

Despite the difficulties outlined above being increasingly acknowledged, and the assertions of Polyani (1966) (amongst others) that experiential knowledge cannot be fully articulated verbally or textually, the traditional (science-based) thesis and the written word continue to be the format demanded by academic institutions and publications. Even where embodied making and learning are intrinsic to or the purpose of the research, scientific methods and justifications are seemingly (thought to be) required (see for example the DRS 2016 Conference Proceedings Vol. 7 Embodied Making and Learning, pp. 2889-2965).[2]

> A cognitive process is not simply what happens inside the brain; a cognitive process can be what happens in the interaction between brain and thing […]
>
> (Malafouris 2013: 67)

[2] The proceedings include my visual essay ‘Code, Decode, Recode: Constructing, Deconstructing and Reconstructing Knowledge Through Making’ (pp.2969-2964), which was presented at the conference as a film.

In recognition of the important role images, objects and hands-on practice play in the generation, understanding and communication of knowledge, academic journals including Craft Research, Artifact Journal of Design Practice and the Journal for Artistic Research (JAR) are actively promoting the use of visual methods of communication, in the form of visual essays, film and "expositions of practice as research" (JAR 2017). Additionally, conferences are beginning to facilitate the dissemination of research practice in alternative formats; the Crafts Council's 'Make:Shift 2016', for example, included: film screenings, practice presentations, a "hands-on material table" and "dynamic research workshops'" (Crafts Council 2016).

> […] by knowing what things are, and how they were made what they are, you gain an understanding about what minds are and how they become what they are […]
>
> (Malafouris 2013: 9)

2.7.1 Visual Communication of Practice-led Research (Rationale)

Ann-Sophie Lehmann asserts that the image is capable of mediating "between the domains of implicit and explicit knowledge." (2012: 13), whilst Pedgley cautions that visual outputs, such as sketches, prototypes and visualisations, "rarely provide a clear account of design thinking" (2007: 466). In response to this and in an attempt to overcome the difficulties of articulating my process and knowledge purely in textual form, I present my research in a combined format by integrating the conventional written format with a 'Visual Essay'. In doing so, I aim to bridge the gap between implicit and explicit knowledge, communicating both more equally to aid clarity and understanding of the thinking and making processes involved. My intention is not to devalue or underestimate the importance of the written word or to suggest that this method of communication can (or should) operate autonomously – the textual narrative is vital to the understanding of the 'visual' narrative.

Images are presented throughout the thesis to "capture the complexity and simultaneity of making" (Lehmann, A 2012: 13) and knowing. Quotations, captions, sketchbook annotations and reflective journal excerpts are used to support and elucidate the 'visual' narrative, as well as to guide the reader through the discussion.

Repeating motions - warping and threading - tracing and imprinting patterns and gestures.

We perceive things by interpreting the information of our senses in the light of what we know of our material culture. We action on them through bodily gesture that changes them, both physically and their meaning as signs. (Dant 2008:11)

Figure 2.4: Preparatory Processes: Warping, Winding-on and Threading (2014)
Film Stills by Anna Piper

2.8 Digital and Material Thinking: Parallel Practices

This section explores the relationship between hand weaving and digital production by identifying similarities in the operation of the hand loom and computer-based systems. It considers how knowledge derived through hands-on making and the mathematical process and notation of weaving can prepare the weaver for working digitally. The section begins with a discussion of the importance of direct physical interaction with materials and processes to establish the knowledge and understanding required to skilfully apply theoretical principles, and predict material and weave structure behaviour.

2.8.1 Hand Weaving: A Mediated Material Experience

Hand weaving is an experience mediated by a machine – the loom. When manually operated, the loom forms an interface between the maker and the materials that curtails sensory (material) feedback. It is during the preparation of the loom, in the process of warping, winding and threading, that significant and prolonged engagement with materials in their uninhibited state occurs (Figure 2.4). In her analysis of Bauhaus weaving practices 'Bauhaus Weaving Theory', Smith states:

> To fully grasp all the options in woven structures afforded by an 8-harness loom, one had to thread the loom by hand.
>
> (2014: 64)

In the dressing of the loom a conscious and intuitive 'reading', internalising and analysing of properties and patterns takes place; ideas are inspired by the yarn's material properties, or "materialness" (Nimkulrat 2010: 74). Yarns transmit signals of how they may behave in weaving, and envisaged ideas and planned designs are deconstructed and worked through mentally in response to the multisensory interaction with materials (Journal Excerpt 2.3). Selections are therefore based on knowledge of the relationship between their "materiality and [potential] expressivity" (Ibid: 65).

2.8.2 Material Thinking: Constructing Knowledge via the Woven Cloth

In hand weaving, the transition from paper plan to material reality, technical principles (threading conventions, density calculations and weave structures) are interrogated, tested and adapted when understood through haptic experience. Taught principles are not abandoned or replaced by experiential knowledge, instead they coexist (Niedderer & Imani 2008) forming "productive relationships between theory and practice" (Lehmann U, 2012: 150).

When weaving begins, the embodied knowledge of an experienced weaver can be drawn upon immediately, allowing them to adapt their actions intuitively in response to the preparatory (and past) material experience(s) and the emerging cloth. Manual operation and repetition over time allow the weaver to physically absorb (embody) and understand the process of textile construction. Through this direct and embodied experience of material, construction techniques and physical process, the weaver can make the successful transition from hand to digital construction. This allows the weaver to construct textiles of greater complexity on a larger scale as well as facilitating more economically viable commercial designs.

2.8.3 The Digital Thinking Weaver

In describing the development of the Jacquard loom by Joseph-Marie Jacquard in 1801, Braddock Clarke & Harris state, "The codification of the human weaver's actions was converted to binary form" (2012: 8), pattern data was transferred onto punched cards that facilitated the lifting and lowering of the warp; an operation that is now controlled digitally. The Jacquard loom, with its binary coding system and punched card mechanism, was the forerunner of modern computing (Kopplin 2002). As a result, weaving and computer programming share a binary language.

The weaver is well versed in the pixel-based imagery of the screen. Weaving's technical notation uses a visual code of grids and squares; each thread and intersection is represented by an individual square (Figure 2.5). The warp design and weave structures are conceived, not as continuous lines (or lengths of thread), but as a pattern of squares that combine to build a "coherent surface" (Ingold 2010: 28) in the mind's eye. This conceptual or 'digital' thinking is clearly advantageous for interpreting digital information and imagery as the weaver moves from the hand loom to computer software.

The loom threading and lifting of the shafts are 'coded' as a series of squares; their interaction creates a grid-based (or pixel-based) image of the intended woven design.

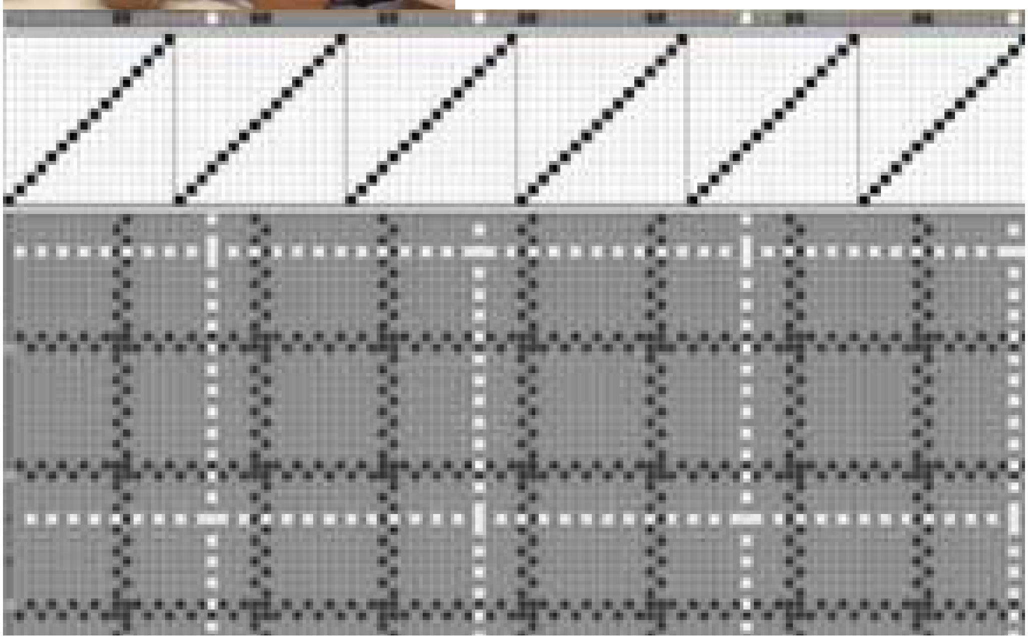


Figure 2.5: Binary Coding of Weaving (2014)
Film Stills and Illustration by Anna Piper

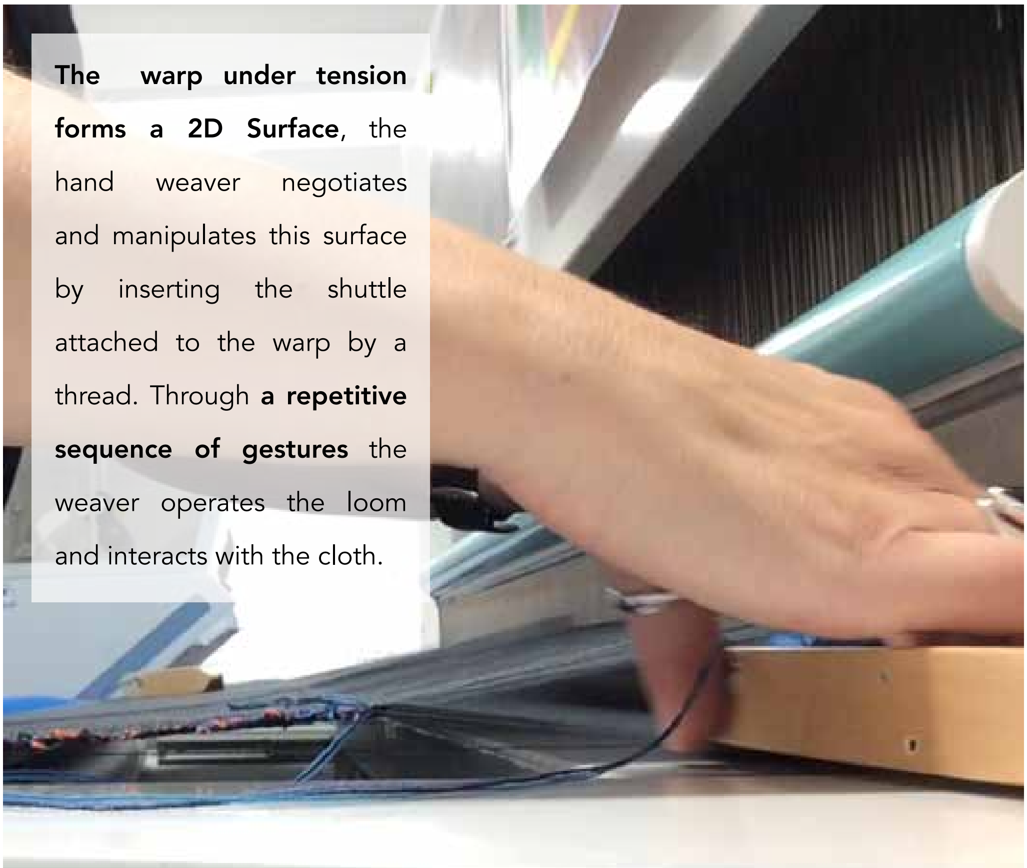


Figure 2.6: Inserting the Weft During Weaving (2018)
Film Still by Anna Piper

2.8.4 Parallel Weaving Practice and Computer Use

Hand weaving, being a machine-mediated activity, prepares the weaver for the "disembodied" (Philpott 2012: 54) experience of digital production (Figure 2.6). When working with digital weaving technologies, such as Jacquard power looms, haptic material and direct machine engagement is largely removed; replaced by digital virtual interfaces and a relationship between the hand and the computer mouse, the eye and the screen (McCullough 1998) (Figure 2.7). McCullough describes a process in which a system is 'read' in multiple ways, the user learns to adapt, identifying patterns and recognising sequences, and the hand begins to work in "complementary modes" (Ibid: 314). However, this activity is informed and sustained by the knowledge and craft skills accrued during hand making. Similarly, parallels can be drawn between weaving and computer use that extend beyond technology being employed as a tool that can be mastered like any other.

The weaver, like the computer programmer, is confronted by a rigid 2D surface (the warp under tension). The 3D vision (of textile, garment, object etc.), is collapsed,

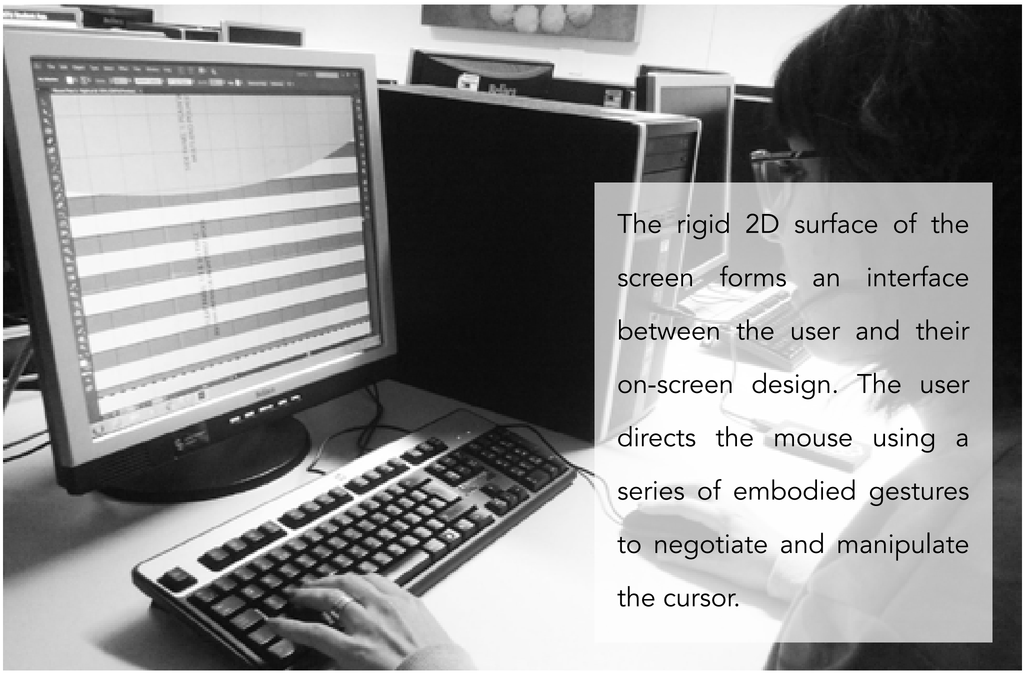


Figure 2.7: Manipulating a Design on Screen (2016)
Photograph by Neil Piper

flattened into a 2D format that is bound by the rules and geometry and limitations of the machine/screen interface; inhibiting the designer's instinct to grab, fold, or manipulate the 2D cloth to assess and/or form the 3D structure. Instead, the 3D form has to be 'unpicked', broken down into its constituent parts, conceptualised and translated via the codes and conventions of the mode of production (Harris 2013).

2.9 Analysis of Established Practice

This section analyses my own hand weaving and digital practice(s). It identifies the differences between the two processes whilst establishing a relationship between the two modes of production, where knowledge acquired through hand construction is critical to the development of digital outcomes and vice versa. It is through this analysis that the Transitional Design Methodology, intrinsic in this research, was formed (Section 3.3).

2.9.1 The Transition from Analogue to Digital Production

When digitising designs, I rely upon my craft knowledge to visualise and evaluate the suitability of different yarn and structure combinations. Digital structures are mentally unpicked, fingers trace out the weft's path as it intersects with the warp, and hands interlock and separate to envisage the divisions and joining of the cloth. Technical

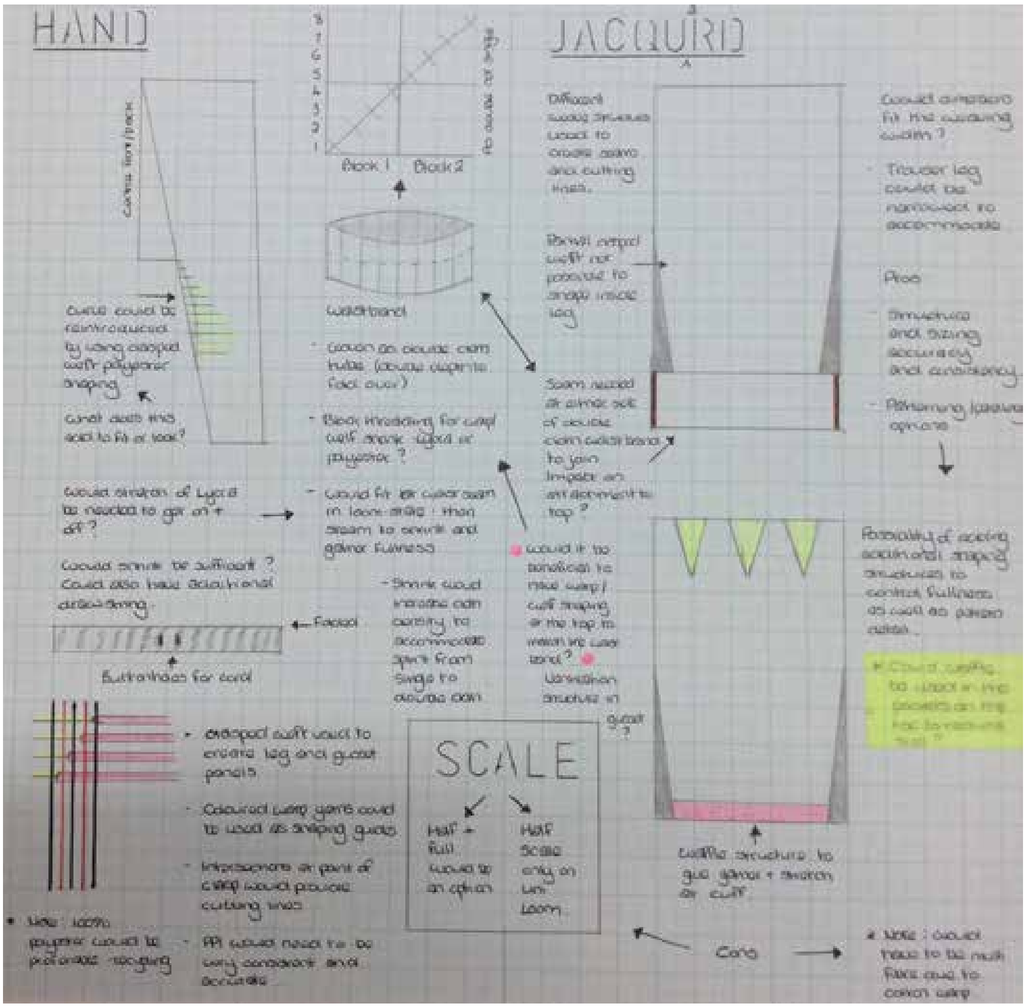


Figure 2.8: Sketchbook Page: Trouser Development Design Options (2017)
Photograph by Anna Piper

knowledge of the machine and its tolerances, derived through past production experience, is also employed in decision-making. This design process is less intuitive than in hand weaving; it actively draws on experiential knowledge in the absence of haptic engagement.

Jacquard production is a hands-off process. The design emerges from the loom and is assessed visually for flaws (in pattern repeat or weave structure), accuracy in scale and yarn positioning, based on the weaver's expectations of the pre-programmed design. Whilst small adjustments can be made to the Jacquard equipment to accommodate structural and material properties and to alter density, other alterations such as changes to weave structure, scale or panel placement, are only possible through reprogramming (Journal Excerpt 2.4). Therefore, a mental "reprogramming of the hand", is required to direct the computer to do what the physical body cannot (Taylor & Townsend 2014).

2.9.2 A Reciprocal Relationship

Being trained as a hand weaver, my design ideas are initially altered and questioned against principles of hand construction. Ideas emerge and are identified through experimentation and examination (on paper or on the loom) as being impossible or impractical on the hand loom due to the constraints it imposes. Digital ideas are conceived in response to these restrictions and capitalise on the capabilities of digital construction. This in turn exposes new possibilities for hand construction in light of the limitations of the digital technologies - a yo-yo-ing between platforms.

Figure 2.8 (sketchbook page) captures the development and questioning of design ideas and decision-making for the trouser prototype based on the different design possibilities insinuated by the hand and digital Jacquard looms, alongside the limitations of both forms of production. These weaving potentialities and limitations apply to yarn use and the application of weave structures, as well as the complexities of garment shaping and construction techniques (Section 7.2).

When the hybrid TC2 loom was introduced into the practice in November 2017, further design opportunities and possibilities were opened up. The loom bridges the gap between hand and Jacquard power loom production. It combines the manual insertion of weft yarns[3] with single-end control[4]. In doing so, it also blurs the boundaries between hand and digital production - the weaver physically engages with the materials and machine during fabric construction, but weave structures and designs are digitally pre-planned and programmed (Figure 2.9). The TC2 brought with it its own (unexpected) limitations and constraints, that could only be fully known and understood through working and engaging with it. Getting to know the new loom and understanding its behaviour was therefore an inherent part of the research.

---

[3] There are no restrictions on weft yarn use or combinations when using manual weft insertion (inserting the weft by hand). Until the introduction of the TC2 this was only possible on the hand loom.

[4] Single-end control is the ability to lift each warp thread independently to create complex patterning and weave structure combinations – until the introduction of the TC2 this was only possible on the the Jacquard loom.

Figure 2.9: Garment Construction on the TC2 Loom Based on a Pre-programmed Design (2018)
Photographs by Anna Piper

2.10 Knowing Through Making: Chapter Conclusion

This chapter has outlined the theoretical framework underpinning the development of the Transitional Design Methodology (Chapter 3). Through the analysis of my existing weaving practice, an iterative relationship between hand and digital design and production processes was identified. When my practical research began (2014) I intended to produce womenswear garment prototypes solely using digital production, restricting hand production to experimental sampling and technical testing of materials and processes. However, the limitations of digital production (detailed in Section 2.9 and discussed in detail in Chapter 7), led to the CPW system being devised to capitalise on the constraints and reciprocal affordances of hand and digital construction; stimulating new ideas and design options for creating garment prototypes. Furthermore, the introduction of the TC2 loom part-way through the research eliminated some of the constraints associated with hand and digital Jacquard weaving, but introduced uncertainty and a new set of limitations and boundaries into my established practice and methodology whilst providing new opportunities for prototype and production.

Six prototype garments have been produced during the research, with two garments being designed for and constructed on each type of loom – hand, digital and hybrid. They each capitalise on the opportunities afforded by each mode of production, whilst working with, being guided by and testing their limitations (in some cases going beyond their limits). In doing so, the garments explore the sustainable and design potential of CPW. Equally, they are a medium for understanding my practice and the process of knowledge making in digital craft practice - they both embody my experience and knowledge, and encapsulate the evolution of the Transitional Design Methodology.

2.11 References

ABBOTT, A. (2004). *Methods of Discovery: Heuristics for the Social Sciences*. London: W.W. Norton & Company Ltd.

AUCH, M. (c.2017). 'Monika Auch, Visual Artist: Profile'. *Monika Auch*. Available at: http://www.monikaauch.nl/. Accessed: 05 January 2018.

AUCH, M. (2016). 'The Intelligence of the Hand'. In: NIMKULRAT, N. KANE, F. & WALTON, K. (Eds.). (2016). *Crafting Textile in the Digital Age*. London: Bloomsbury. pp. 61-73.

BARRETT, E. (2007). 'Studio Enquiry and New Frontiers of Research'. *Studies in Material Thinking* .1(1). pp.1–3. Available at: https://www.materialthinking.org/sites/default/files/papers/Estelle.pdf. Accessed: 29 September 2016.

BATH SPA UNIVERSITY. (c.2016). 'Tim Parry Williams Profile'. *Bath Spa University*. Available at: https://www.bathspa.ac.uk/our-people/tim-parry-williams/. Accessed: 05 January 2018.

BRADDOCK CLARKE, S, E. & HARRIS, J. (2012). *Digital Visions for Fashion + Textiles: Made in Code*. London: Thames and Hudson Ltd.

BRAITHWAITE, N. (2017). 'Sensing Creativity: The Role of Materials in Shoe Design'. *The Senses and Society*. 12(1). pp. 90-94.

CAMPBELL, J, R. (2016). 'Forward'. In: NIMKULRAT, N. KANE, F. & WALTON, K. (Eds.). (2016). *Crafting Textile in the Digital Age*. London: Bloomsbury. pp. XIX - XXIII.

CARDOSO, R. (2008). 'Craft Versus Design: Moving Beyond a Tired Dichotomy'. In: ADAMSON, G. (Ed.) *The Craft Reader*. Oxford: Berg. pp. 321–332.

CRAFTS COUNCIL. (2016). 'Make:Shift'. *Crafts Council*. Available at: http://www.craftscouncil.org.uk/what-we-do/makeshift/. Accessed: 20 July 2016.

DANT, T. (2008). The Pragmatics of Material Interaction'. *Journal of Consumer Culture*. 8(1). pp.11–33.

DE FREITAS, N. (2002). 'Towards a Definition of Studio Documentation: Working Tool and Transparent Record'. *Working Papers in Art and Design*. 2. pp. 1–10.

DOLOUGHAN, F. (2002). 'The Language of Reflective Practice in Art and Design'. *Design Issues*. 18(2). pp. 55–65.

DORMER, P. (1994). T*he Art of the Maker: Skill and its Meaning in Art, Craft and Design*. London: Thames & Hudson.

DREYFUS, H, L. & DREYFUS, S, E. (1986). *Mind Over Machine: The Power of Human Intuition and Expertise in the Era of the Computer*. Oxford: Basil Blackwell.

DRS. (2016). DRS 2016: 'Design + Research + Society, Future-Focused Thinking'. In: *Proceedings of DRS2016: Design + Research + Society Future-Focused Thinking*. Vol.7 Embodied Making and Learning. pp. 2889-2965.

ENGLISH, B. (2011). *Japanese Fashion Designers: The Work and Influence of Issey Miyake, Yohji Yamamoto and Rei Kawakubo*. Oxford: Berg.

FRAYLING, C. (2011). *On Craftsmanship: Towards a New Bauhaus*. London: Oberon Masters.

FRAYLING, C. (1993). 'Research in Art and Design'. *Royal College of Art Research Papers*. 1(1). pp. 1-5. Available at: http://researchonline.rca.ac.uk/384/3/frayling_research_in_art_and_design_1993.pdf. Accessed: 12 December 2017.

GOLDSWORTHY, K. (2012). 'Laser Finishing: A New Process for Designing Recyclability in Synthetic Textiles'. (PhD Thesis). London: University of the Arts London.

GRAY, C. & MALINS, J. (1995). 'Appropriate Methodologies for Artists, Designers & Craftspersons: Research as a Learning Process'. *Carole Gray*. Available at: http://carolegray.net/Papers%20PDFs/cc.pdf. Accessed: 12 April 2014.

GROTH, C. (2017). 'Making Sense Through Hands: Design and Craft Practice Analysed as Embodied Cognition'. (PhD Thesis). Helsinki: Aalto University School of the Arts, Design and Architecture.

HARRIS, J. (2013). 'Digital Skin: How Developments in Digital Imaging Techniques and Culture Are Informing the Design of Futuristic Surface and Fabrication Concepts'. *Textile: The Journal of Cloth and Culture*. 11(3). pp. 242–261.

HARRIS, J. (2012). 'Digital Practice in Material Hands: How Craft and Computing Practices Are Advancing Digital Aesthetic and Conceptual Methods'. *Craft Research*. 3(1). pp. 91–112.

HASEMAN, B. & MAFE, D (2009) 'Acquiring Know-How: Research Training for Practice-Led Researchers'. In: SMITH, H. & DEAN, R, T. (Eds.) *Practice-Led Research, Research-Led Practice in the Creative Arts. Research Methods for the Arts and Humanities.* Edinburgh: Edinburgh University Press. pp. 153–165.

HOWARTH, D. (2016). 'Issey Miyake Bakes Fabric to Pleat Spring Summer 2016 Garments'. *Dezeen*. Available at: Link: http://www.dezeen.com/2016/01/08/spring-summer-2016-fashion-collection-issey-miyake/. Accessed: 20 June 2016.

HOWARTH, D. (2014). 'Issey Miyake's focus is "being innovative with technology" says head of womenswear'. *Dezeen*. Available at: http://www.dezeen.com/2014/11/12/issey-miyakeyoshiyuki-miyamae-interview-3d-stretch-seam-fashion-technology/. Accessed: 20 June 2016.

IDEAS ON DESIGN. (2013). 'Creative Masters: Reiko Sudo'. *Ideas On Design*. Available at: http://ideasondesign.net/speakers/speakers/reiko-sudo/. Accessed: 06 May 2017.

INGOLD, T. (2010). 'Transformations of the Line: Traces, Threads and Surfaces'. *Textile*. 8(1). pp.10–35.

ISSEY MIYAKE. (c.2016). 'Making Things'. *Issey Miyake Inc*. Available at: https://www.isseymiyake.com/en/brands/isseymiyake/making. 05 January 2018.

JAR. (2017). 'About: Journal for Artistic Research'. *Journal for Artistic Research*. Society for Artistic Research. Available at: http://jar-online.net/about-jar/. Accessed: 08 September 2018.

JIANG, K. (2009). 'Time and Temperature'. In: SANDU CULTURAL MEDIA CO LTD. (Ed.) (2009). *Fabric: Metallic Textile Design of Kinor Jiang*. Hong Kong: Sandu Publishing Co Ltd. pp. 25-47.

JOHNSTONE, L. (2015). *Digital Handmade: Craftsmanship and the New Industrial Revolution*. London: Thames and Hudson.

KANE, F. (2013). 'Publication Review: Digital Visions in Fashion + Textiles: Made in Code, Sarah E. Braddock Clarke and Jane Harris 2012'. *Craft Research*. 4(2). pp. 289–292.

KOPPLIN, J. (2002). 'An Illustrated History of Computers Part 2'. *Computer Science Lab*. Available at: http://www.computersciencelab.com/ComputerHistory/HistoryPt2.htm. Accessed: 29 September 2016.

LEHMANN, A, S. (2012). 'Showing Making: On Visual Documentation and Creative Practice'. *The Journal of Modern Craft*. 5(1). pp.9–23.

LEHMANN, U. (2012). 'Making As Knowing: Epistemology and Technique in Craft'. *The Journal of Modern Craft*. 5(2), pp.149–164.

LINDQVIST, R. (2015). 'Kinetic Garment Construction: Remarks on the Foundations of Pattern Cutting'. (PhD Thesis). Boras: The Swedish School of Textiles, University of Boras.

MALAFOURIS, L. (2013). *How Things Shape the Mind: A Theory of Material Engagement*. Cambridge: MIT Press.

MALAFOURIS, L. (2005). 'The Cognitive Basis of Material Engagement: Where Brain, Body and Culture Conflate'. In: DE MARRAIS, E. GODSEN, C. & RENFREW, C. (Eds.) R*ethinking Materiality: The Engagement of Mind with the Material World*. Cambridge: McDonald Institute for Archaeological Research.

MARGETTS, M. (2018). 'The Growing is the Thing'. *Crafts Magazine*. No. 274. Sept/ Oct 2018. pp. 36-44.

MCCULLOUGH, M. (1997). 'Abstracting Craft: The Practiced Digital Hand'. In: ADAMSON, G. (Ed.) *The Craft Reader.* Oxford: Berg. pp. 310-316.

NIEDDERER, K. & IMANI, Y. (2008). 'Developing a Framework for Managing Tacit Knowledge in Research Using Knowledge Management Models'. In: *Undisciplined! Design Research Society Conference*. Sheffield: Sheffield Hallam University. Available at: http://shura.shu.ac.uk/507/. Accessed: 01 August 2014.

NIEDDERER, K & TOWNSEND, K. (2014). 'Designing Craft Research: Joining Emotion and Knowledge'. *Design Journal*. 17(3). pp.624–647.

NIMKULRAT, N. RAEBILD, U. & PIPER, A. (Eds.) (2018). 'Soft Landing of Fashion and Textile Education' Cumulus Think Tank Series. Helsinki: Aalto University, School of Arts, Design & Architecture.

NIMKULRAT, N. (2010). 'Material Inspiration: From practice-led research to craft art education'. *Craft Research.* Vol. 1. pp. 63-84.

PAINE, H. (2016). 'Laser Shaping: A Method for Controlling the Elastic Behaviour of Stretch Fabrics for a Targeted and Graduated Compressive Effect on the Body'. (PhD Thesis). London: Royal College of Art.

PALLASMAA, J. (2009). *The Thinking Hand*. Chichester: John Wiley & Sons.

PARRY-WILLIAMS, T. (2015). 'Made-by-Hand: [Re]evaluating Traditional (Japanese) Textile Practices for Contemporary Design'. *Craft Research*. 6(2). pp.165-186.

PARRY-WILLIAMS, T. (2007). 'Craft: Industry Interface – A dialogue between hand, heart and machine (an Anglo-Japanese collaboration)'. In: Follett, G. & Valentine, L. (Ed.). *New Craft – Future Voices Conference Proceedings.* Dundee: Duncans of Jordanstone College of Art & Design. pp. 73-85

PEDGLEY, O. (2007). Capturing and Analysing Own Design Activity'. *Design Studies.* 28(5). pp.463–483.

PHILPOTT, R. (2012). 'Crafting Innovation: The Intersection of Craft and Technology in the Production of Contemporary Textiles'. *Craft Research*. 3(1). pp. 53–74.

PHILPOTT, R. (2011). 'Structural Textiles: Adaptable Form and Surface in Three Dimensions'. (PhD Thesis). London: Royal College of Art.

PIPER, A. (2016). 'Code, Decode, Recode: Constructing, Deconstructing and Reconstructing Knowledge Through Making'. In: *Proceedings of DRS2016: Design + Research + Society Future-Focused Thinking*. Vol.7 Embodied Making and Learning. pp. 2889-2965. https://static1.squarespace.com/static/55ca3eafe4b05bb65abd54ff/t/57489ca504426269f1c93e60/1464376485529/415+Piper.pdf. Accessed: 10 November 2018. POLANYI, M. (1966). *The Tacit Dimension*. (Reissue Edition). London: University of Chicago Press.

PRESS, M. & COOPER, R. (2003). *The Design Experience: The Role of Design and Designers in the Twenty-First Century*. Aldershot: Ashgate.

PYE, D. (1968). *The Nature & Art of Workmanship*. Cambridge: Cambridge University Press.

RISSANEN, T. (2013). 'Zero-Waste Fashion Design: A Study at the Intersection of Cloth, Fashion Design and Pattern Cutting'. (PhD Thesis). Sidney: University of Technology Sidney.

SCHILLIG, G. (2015). 'On Skins, Membranes and Folds: Textile spaces – spaces of communication. *Craft Research*. 6(2). pp. 297-205.

SCHÖN, D, A. (1991). *The Reflective Practitioner: How Professionals Think in Action.* London: Ashgate.

SMITH, T. (2014). *Bauhaus Weaving Theory: From Feminine Craft to Mode of Design.* London. University of Minnesota Press.

TAYLOR, J. (2015). 'The Technical Designer: A New Craft Approach for Creating Seamless Knitwear'. (PhD Thesis). Nottingham: Nottingham Trent University.

TAYLOR, J. & TOWNSEND, K. (2014). 'Reprogramming the Hand: Bridging the Craft Skills Gap in 3D/digital Fashion Knitwear Design'. *Craft Research*. 5(2). pp.155–174.

TOWNSEND, K. (2004). 'Transforming Shape: A Simultaneous Approach to the Body, Cloth and Print for Textile and Garment Design (synthesising CAD with Manual Methods)'. (PhD Thesis). Nottingham: Nottingham Trent University.

2 Journal Excerpts

Warping with Extras (Excerpt 2.1)

Posted: 23rd June 2014

[...] The yarn is one that I am familiar with so I am not overly focussed on it (i.e. checking how it sits on the warping mill as it wraps around) - I am aware of its smoothness in my fingers, constantly feeling the flow of it running through. If held too tightly it begins to dig in to the fingers and so the tension is loosened. It feels in my hands as though it is drying the skin - I recognise/remember this from working with the yarn before. Despite being soft and smooth, and although the yarn does not tangle, snag or stick in the process, I know (again from experience) that this dryness may be a signal that the yarn will be sticky during winding on. There are however, no fibres rubbing off the yarn (there is no fluff on the warp or on the wood of the mill), again an indication of its smoothness and compactness and that it should not fur up and connect together with adjacent ends during winding and threading.

Now on reflection, I am thinking about the signs and signals that the yarn is giving during the process of warping - the yarn at no point breaks, if I pull the mill backwards using the yarn (having made a mistake in my warping action) it returns without stretch or snap - it is strong. Running through my fingers and at times through my nails, it does not abrade the yarn (hence the lack of loose fibres) - suggesting that the yarn is unlikely to snap during weaving.

Removing the warp from the mill, creating the chain to hold the yarns – neat and tidy ready for winding on. I am always pleased when warping is complete – it is not the most exciting activity and I am a step closer to weaving.

Tagged: *Intuition, Knowledge Application, Material Engagement*

I Love Weaving (but not all of the time)! (Excerpt 2.2)

Posted: 28th September 2015

I have had an amazing day! Everything has come together. I have completed more samples in a single day than I have been doing in a week. Today is one of those days that remind me why I am a weaver and why I love it (sometimes) […]

The smoothness and efficiency of the weaving shows in the samples, they are consistent and even. Again, they were yarn-testing samples and so it was simply a case of following the basic lifting plan and alternating between active and passive yarns until the sample was the required size (6 inches) […]

Even whilst on the loom the pleating effect has already started to show – this will only become greater when the samples are removed and finished. It occurred to me that this is because the same shaping is being applied for the whole sample – the floats (and therefore the folds) are the full length of the cloth (they repeat along the same line) rather than changing direction. Perhaps, in the last samples, the changes were too frequent – the shaping was on a too small scale and there was not enough of the same float to manipulate the cloth. Therefore, by increasing the scale of the patterns a number of floats in the same position could be used to increase its strength and ability to manipulate.

By the end of the day I had run out of warp. It is probably not true, but it always feels like things start to go well and come together just as the warp comes to an end. But today has really inspired me. I just want to get another warp on and keep weaving […]

Tagged: *Ideas, Immersion, Problem-solving*

Time to Think (Excerpt 2.3)

Posted: 1st September 2015

[...] During the process of threading and working through the pattern (both physically and in my mind) I realised there was an issue with the threading plan - the odd number of blocks in the first and final sections, alongside the even number of blocks in the central section would mean that if a combination of warp and weft-facing structures was applied across the width of the cloth, a larger than intended stripe of a single weave structure would occur where the second and third blocks meet. Although simple to resolve, by switching the blocks in the final section, this would have been an annoying 'flaw' in some of my planned samples.

Tagged: *Impact, Time, Planning, Problem-solving*

Out of My Hands (Excerpt 2.4)

Posted: 12th November 2014

[...] I then moved on to testing the folding designs (not using the active yarns) to check the structures and scales. The structures are as they should be but the scale of the designs needs to be reduced by approx. 50% to achieve the intended scale of the original design. I knew (based on past experience) that some scaling would be required, but wanted to see them constructed to make appropriate changes and calculations.

Although it is usual that using a machine of this type creates a barrier, in this case it is even more extreme. The process is one of observation, some measurements and running my hand over the taut cloth - it feels as though much of the decision making is out of my hands. It is difficult to gain any true knowledge about the way the fabric may handle or react whilst it is under tension on the loom, although it is possible to assess the placement, position and suitability of the structure from inspection of the cloth and the way the loom operates (bouncing if the structure is too tight for example).

The process is not only non-participatory, it is also disjointed and non-responsive (not the right word) - the design is developed digitally before moving to the loom to see if what has been programmed is correct or desirable, if not, further programming takes place at a later time away from the loom once more. In the university setting this all takes place over a period of days (or even weeks) and so any sort of flow or fluid process is limited. As such, ideas cannot be acted upon immediately - how does this effect the creative process?

Tagged: *Control, Decision-making, Delay/Immediacy, Material Engagement, Process Constraints*

3 Transitional Design:
Research Methods and Methodology

3 Transitional Design:

Research Methods and Methodology

3.1 Transitional Design: Chapter Overview

This chapter describes the identification and development of the Transitional Design Methodology. The methodology was designed to facilate the construction of zero waste woven garments that explore the capabilities of hand, digital and hybrid production techniques, as well as investigating the role embodied weaving knowledge plays in informing textile design innovation.

The methodology evolved throughout my MA studies (2013) as an instinctive creative process, and was recognised, formalised, tested and developed during this PhD research. The chapter discusses, in detail, the research structure and the selected reflective methods designed to encourage the transitional dialogue between hand and digital production that is intrinsic to this approach. Moreover, it examines the importance of the creative constraints imposed by the weaving equipment and technologies being used, and the impact of introducing new technologies part-way-through the project on the established methodology.

The research operates within a framework of creative, experimental, first-person action research (Trullen & Torbert 2013; Reason & Bradbury 2001). It adopts a rigorous approach to practice analysis and self-reflection, whereby the key principles of technical functionality, design aesthetics and sustainable design are considered in parallel and are integrated throughout the design and production process. This approach draws from craft, design thinking and sustainability theories, including: heuristic thinking (applied by designers in both zero waste pattern cutting and whole garment knitting), Lawson's "parallel lines of thought" (2006) and Lehmann's "Making as Knowing" (2012). All of these were fundamental in the identification and development of the Transitional Design Methodology upon which this research is founded.

3.2 Composite Pattern Weaving: Phases of Development

Composite Pattern Weaving (CPW) requires the parallel designing of the woven textile and the garment, where style, structure, composition, functionality and sustainability converge. In order to address and develop each of these intrinsic components, the process involves the following two development phases using hand, digital and hybrid looms (see Sections 2.9.2 and 7.2 for details of the hybrid TC2 loom's capabilities and specification):

Phase #1 – Component Construction: the testing of yarns, weave structures and weaving techniques to establish and develop effective, functional, flexible and readily reproducible fabric shaping and construction methods.

Phase #2 – Garment Construction: the alignment of multiple integral fabric shaping techniques within the garment prototypes (Figure 3.1) to examine their flexibility, reproducibility and sustainability, and to generate designs that perform both functionally and aesthetically.

These stages integrate the development of hand and digital production; they adopt a parallel approach to practice (hand/digital and textile/fashion processes) (Section 3.6) with methods of analysis and reflection aligned to facilitate the advancement of process and outcome (Sections 3.4 and 3.5).

This parallel (or integrated) approach builds upon a "Simultaneous Design Method" established by Townsend (2004a), in which garment shapes and printed textile designs were developed simultaneously through manual and CAD based modelling, to produce engineered designs "that were empathetic to both garment and form" and provided designers with the "ability to envision and integrate 2D surface designs with prospective 3D forms." (Townsend 2004b: 21). In this research, a Simultaneous Design Method is applied to the design of woven structures and textile composition, garment construction and pattern lay-planning.

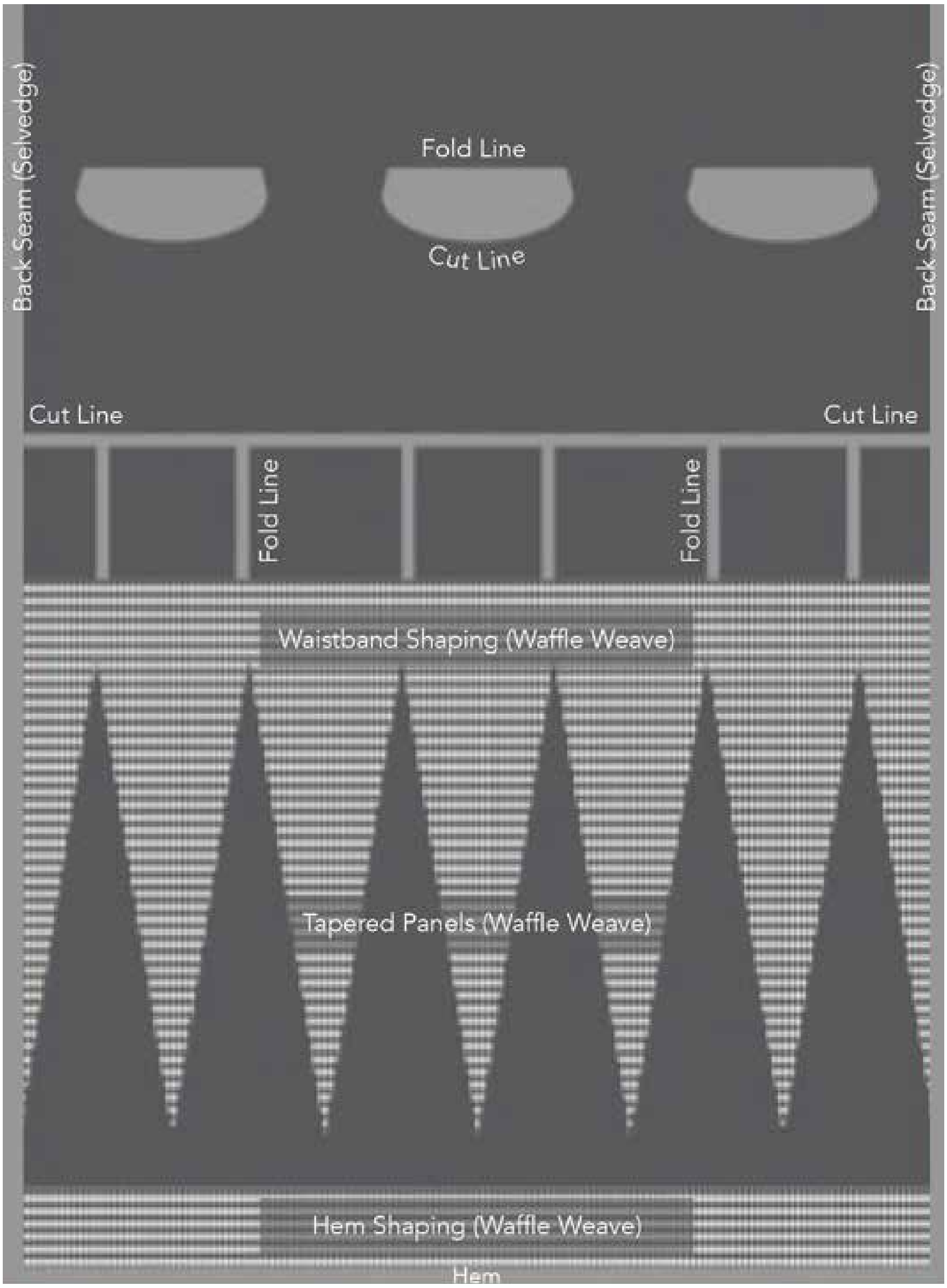


Figure 3.1: Dress Lay-plan with Weave Structures Positioned to Shape and Fit the Garment (2018) Illustration by Anna Piper

By aligning the usually discrete phases of fashion design and production (Gwilt 2011), textile/garment functionality, waste generation, material sustainability and aesthetic elements (such as colour, pattern and scale) are examined (and addressed) at the design stage. The implications of design decisions and their "problems" and/or "potentials" (Schön 1991: 99) can be identified and evaluated, accepted or rejected by the

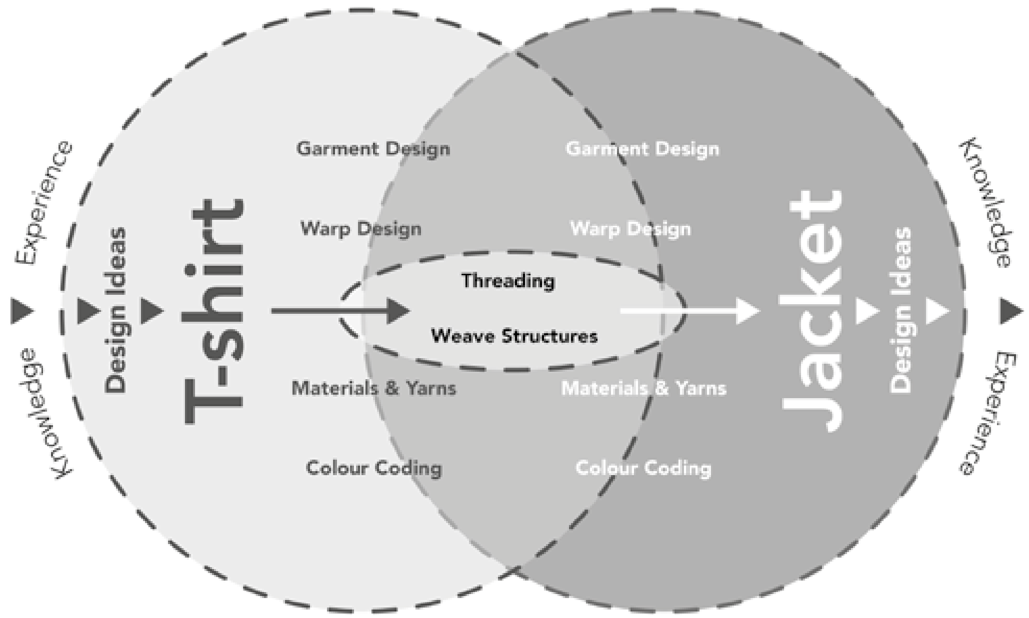


Figure 3.2: The ‘Conversation’ Between the T-shirt and Jacket Designs (2018)
Illustration by Anna Piper

designer[1]. Furthermore, the consideration of textile/garment construction alongside waste elimination/generation during the design process facilitates a ‘conversation’ between garments, where the design of one garment informs the next as a means of optimising waste utilisation (Section 7.10) - garments are therefore iterative, logical and creative (Figure 3.2).

3.3 The Transitional Design Methodology

This design methodology (Figure 3.3) situates the maker at the centre of creative reflective practice, where analogue and digital design and production take place in tandem. By employing the two practices in parallel, concepts, designs and ways of

[1] Schon talks of a “literal logic of design” Schön 1991: 99) i.e. if a decision (or move) is made, there will a resultant impact (implications) elsewhere. He refers to these implications as either “problems” or “potentials” to be either accepted or rejected. In making moves, the designer must be aware that a wrong choice in a single domain/element can ruin the whole. In this research, the key areas for consideration (domains) are technical functionality, sustainability and design aesthetic, which are aligned with the criteria for analysis and evaluation outlined in Section 3.5.

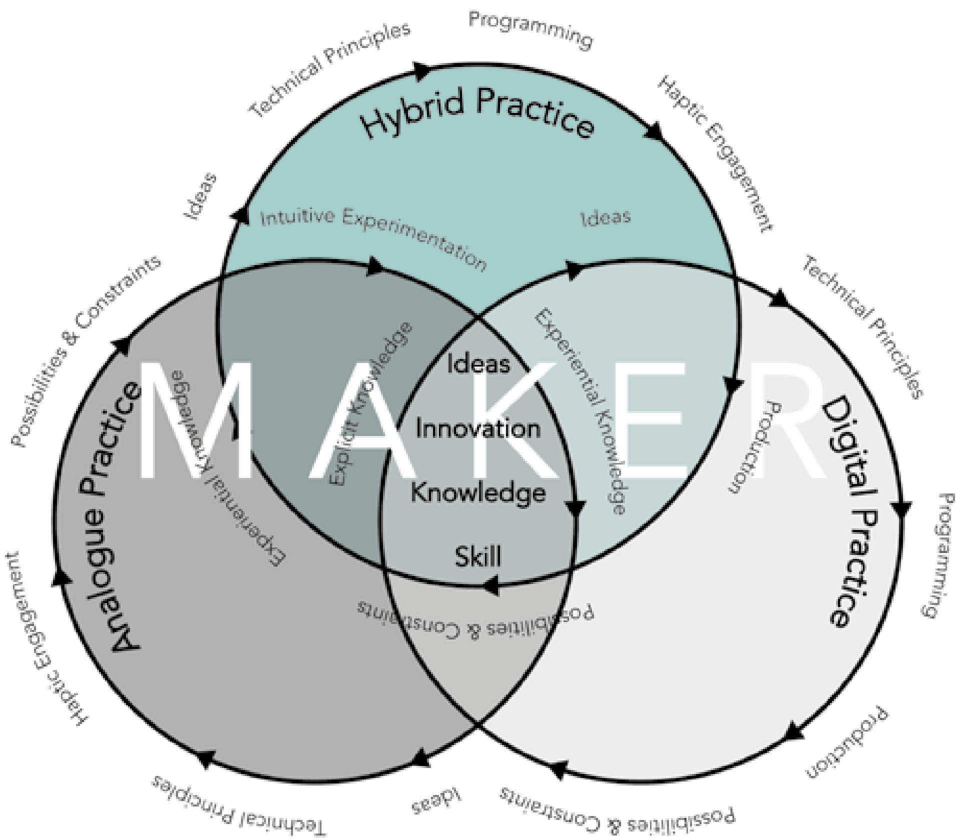


Figure 3.3: The Transitional Design Methodology (2018)
Illustration by Anna Piper

working can evolve as the maker moves between modes. Ideas are conceived and explored within the boundaries of one process, but are also transferred, expanded and developed to capitalise on the affordances of the other. Just as digital outcomes rely on embodied craft knowledge, hand outcomes depend on the experience of digital construction – they become mutually beneficial. The interrogation and assimilation of skills, methods and design principles challenges existing thinking and conventions by establishing a transitional dialogue and knowledge transfer between hand and digital production, and textile and fashion construction (see the relationships between hand and digitally woven trousers (Section 7.5), the t-shirt (Section 7.6) and dress (Section 7.7)).

3.3.1 Identifying the Iterative Approach

> Contemporary textiles practice requires the designer/maker to identify and negotiate a path between both hand and digital processes.
>
> (Nimkulrat et al. 2016:10)

The iterative approach to hand and digital weaving that is central to the Transitional Design Methodology originated in my MA studies (2013). It was not a conscious decision or pre-planned methodology, but instead the natural evolution of my practice and working processes. The approach did not become evident until the project was completed, and reflective journals were reviewed in the early stages of this research[2].

Journal entries that detailed activities being undertaken, design ideas and decisions, as well as reflections on process and progress, highlighted that hand and digital sampling and garment weaving took place concurrently throughout the project (Figure 3.4). Although the two approaches were viewed as distinct during the project itself (fabric or garment developments were always identified as 'Jacquard development' and 'Hand woven development') it is clear that they were interconnected.

Knowledge and understanding of fibre properties, weave structure characteristics and the complexities of woven construction (such as the lowering and lifting requirements to produce multiple cloths simultaneously), derived through working on both hand and digital looms, were transferable between modes of production. This was particularly apparent when methods were being sought to visually connect the fabric and garments being produced digitally and by hand, through application of colour, weave structure, pattern and yarn usage (Journal Excerpt 3.1 - Weeks 41 and 44).

There was also some evidence to suggest that hand and digital weaving processes informed one another, and that garment designs were interconnected rather than independent. This is evident both through textual annotations and in the grouping of images within the reflective journal which illustrate the shared use of weave structures, and the evolution of garment shapes (Journal Excerpt 3.1 - Weeks 28 and 37). Furthermore, journals and sketchbook annotation indicated that design thinking and design ideas responded to the construction limitations imposed by the mode of production, such as the ability to produce tessellating garments to eliminate waste (Journal Excerpt 3.1 - Week 28).

---

[2] The review of MA practice took place when writing the paper 'Crafting the Composite Garment: The Role of Hand Weaving in Digital Production/Creation' for Huddersfield's University's 'Transitions: Re-thinking Textiles and Surfaces' (2014). This paper and resulting article by Piper and Townsend, published in the 'Journal of Textile Design Research and Practice' (2015), was instrumental in the identification of the transitional design approach and methodology.

WEEK 10	Handwoven Sampling	
WEEK 11	Handwoven Sampling and Garment Design	
WEEK 12		
WEEK 13		
WEEK 14	Handwoven Garment Production	
WEEK 15		
WEEK 16		
WEEK 17		
WEEK 18		
WEEK 19	Handwoven Garment Production	
WEEK 20		
WEEK 21	Handwoven Technical Sampling	
WEEK 22		
WEEK 23		
WEEK 24		
WEEK 25		
WEEK 26		Jacquard Sampling CAD Development
WEEK 27	Handwoven Technical Sampling	Jacquard Sampling
WEEK 28		
WEEK 29	Handwoven Garment Component Prototyping	
WEEK 30	Handwoven Garment Design Development	Jacquard Garment Design Development
WEEK 31		
WEEK 32	Handwoven Garment Component Prototyping	
WEEK 33		
WEEK 34		Jacquard Sampling
WEEK 35		Jacquard Garment Prototyping
WEEK 36	Handwoven Garment Design Development	Jacquard Garment Design Development
WEEK 37	Handwoven Garment Prototyping	
WEEK 38		
WEEK 39		Jacquard Sampling and Garment Prototyping
WEEK 40	Handwoven Sampling and Garment Design Development	
WEEK 41	Handwoven Sampling	
WEEK 42		
WEEK 43		Jacquard Sampling and Garment CAD Development
WEEK 44		
WEEK 45	Handwoven Dress Design Development	
WEEK 46		
WEEK 47	Handwoven Dress Production	Jacquard Bodice Production
WEEK 48	Handwoven Dress and Jacket Production	
WEEK 49	Handwoven Jacket Production	

Figure 3.4: MA Research Timeline (2018)
Illustration by Anna Piper

	Advantage	Constraint
Hand Weaving	• Freedom of yarn usage • Manual manipulation of yarns • Selective weaving of sections of the warp • Instant adjustment of density in response to yarns and weave structures	• Fixed number of shafts limits structure and pattern combinations and placement • Garment silhouettes (generally) restricted to angular geometric shapes
Digital Jacquard Weaving	• Single-end control facilitates complex structure combination and placement • Single-end control facilitates complex garment silhouettes (including curves and contours)	• The loom's predetermined tolerances limits yarn usage • Design and structure alterations require reprogamming

Table 3.1: Advantages and Constraints of Hand and Digital Construction

3.3.2 Establishing the Iterative Approach

Whilst the model shown in Figure 3.3 evolved over time, the principles derived from the instinctive creative process identified in my MA studies (2013) (Figure 3.4) shaped this research's design and instigated the development and application of the Transitional Design Methodology.

> […] freedom comes from knowing what to do with constraints when they emerge, finding the right constraints in the right balance, and crafting an environment in which they can be perceived as opportunities rather than obstacles.
>
> (Rosso 2014: 582)

At the heart of the methodology are the boundaries (or creative constraints) imposed by each mode of production (Table 3.1 – Chapter 7 provides full details of the constraints and advantages of each loom used in the research). They provide a framework for design and decision-making as well as opportunities for creativity and innovation. Neither hand nor digital weaving is considered hierarchically superior (or preferable); hand production is not regarded as a precursor to digital production (as seen in other

PhD studies (see Taylor 2015; Philpott 2011; Townsend 2004)), instead it is expected that each form of construction will produce different fabric qualities and garment types.

> […] it is important not to look only for new concepts driven by contemporary technology, but also to have an appreciation for textile craft history, as there lies great sources of inspiration for textile innovations […] Just because a particular quality of fabric cannot currently be woven on a power loom, does not negate its potential to be commercially produced.
>
> (Thomas 2009: 152)

Reflective research methods (Section 3.4) and research phases (Section 3.5) were designed to actively encourage an iterative approach to hand and digital design, through simultaneous experimentation, design and production of textiles and garment prototypes using hand and digital weaving (Figure 3.5), supported by thorough reflective practice (Section 3.4). It was hypothesised that integrating hand and digital methods 'in parallel' would catalyse opportunities for innovation in hand and digital weaving to push the boundaries of both forms of production.

3.3.3 Destabilising the Iterative Approach

Having identified and understood the relationship between hand and digital practices (in my creative process) to establish the Transitional Design Methodology, part way through the research a third 'hybrid' loom was introduced. The loom was ordered in early 2015 but, due to a number of unforeseen complications with the installation of the TC2, it was not available for use until November 2017. As such, its introduction was anticipated and could be planned for, but the true impact and capabilities of the loom were not known until sampling and garment prototype production took place between February and September 2018 (Sections 7.9 and 7.10).

> The loom is primarily a Sampling and Rapid Prototyping loom, and the output is woven hardcopies. Our loom is computer-controlled and manually operated because it is designed to be operated by the creator/designer/weaver.
>
> (Digital Weaving Norway c.2018)

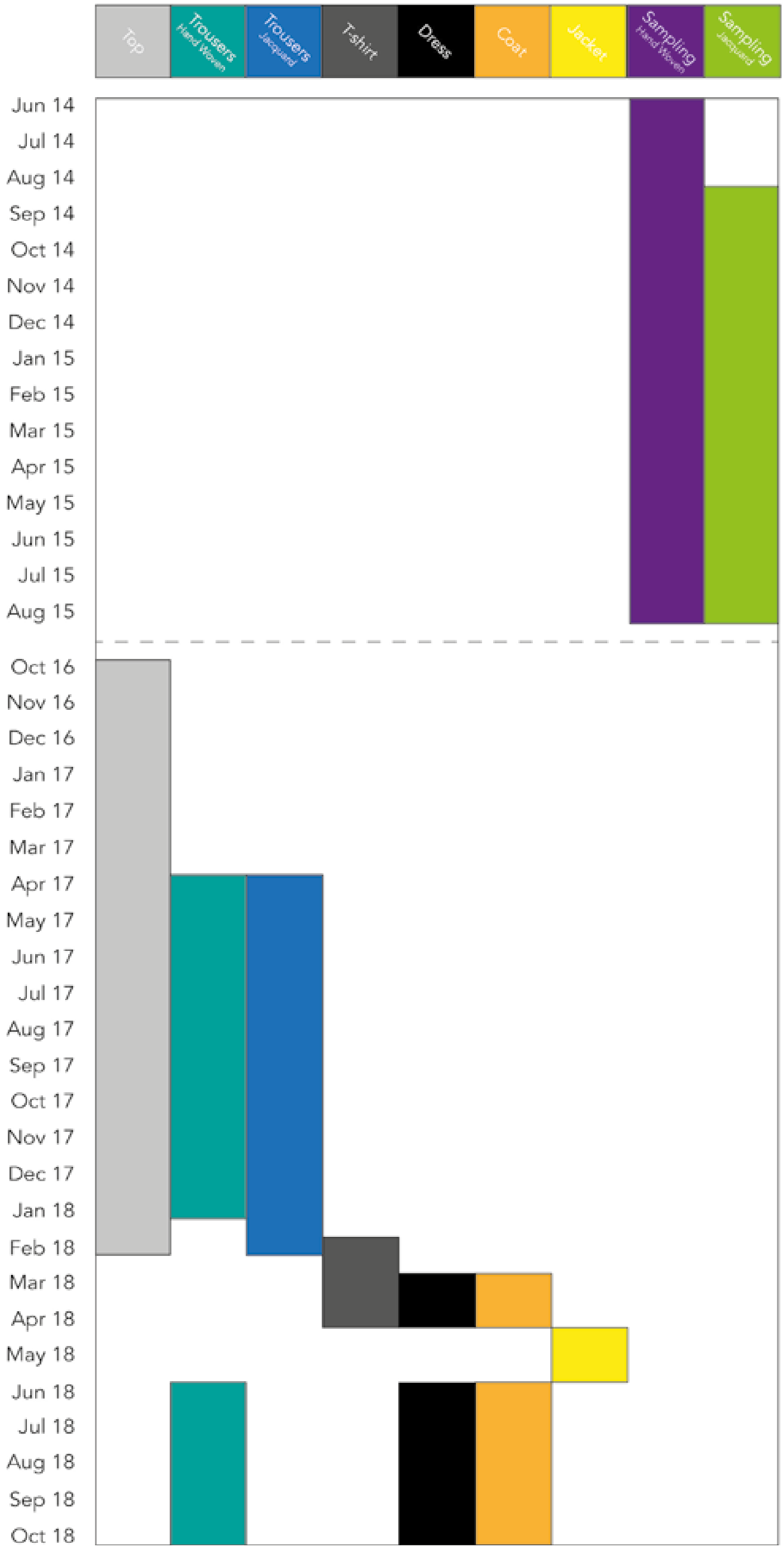


Figure 3.5: Woven Production Timeline (2018)
Illustration by Anna Piper

Loom Capability	Dobby Loom (Hand)	TC2 Loom (Hybrid)	Jacquard Power Loom (Digital)
• Freedom of yarn usage (weft)	✓	✓	X
• Predetermined warp set-up/specification (yarn type, width, density)	X	✓	✓
• Manual/direct manipulation of yarns	✓	✓	X
• Selective weaving of sections of the warp	✓	✓	X
• Instant adjustment of density in response to yarns and weave structures	✓	X	X
• Single-end control to facilitate complex structure combination and placement	X	✓	✓
• Single-end control to facilitate complex garment silhouettes (including curves and contours)	X	✓	✓
• Fixed harness width/pattern repeat	X	X	✓
• Digital programming of weave structures/ design	X	✓	✓

Table 3.2: Loom Capabilities: Dobby, TC2 and Jacquard Power Loom

As a computer-controlled but manually operated Jacquard loom, the TC2 loom bridges the gap between hand and digital production, by removing many of the boundaries of construction imposed by the existing hand and digital Jacquard power loom (Section 3.3.3) and as such the established framework for design and decision-making was removed. Table 3.2 summarises the capabilities of each type of loom being used in the research – further details relating to individual loom set-up and specifications are outlined in Section 7.2.

> Great freedom can be a hindrance because of the bewildering choices it leaves us, while limitations, when approached open-mindedly, can spur the imagination to make the best use of them and possibly even overcome them.
>
> (Albers 2000: 67)

The removal of construction boundaries through the introduction of the TC2 destabilised the recently established methodology and design process (Section 3.3.2

and 3.6.2). The process of threading the TC2 (August 2016) led me to question the validity and suitability of the transitional methodology as it is predicated on designs being developed in response to the constraints and advantages of the individual modes of production. The TC2 loom seemingly removed (or transcended) these limitations (Table 3.2).

> Usually when threading the loom, it is a time of reflection - a time to consider and develop ideas. But in this particular case this did not happen. When threading the hand loom, I spend my time thinking about the things that I can produce with that particular threading […] Reflecting on this whilst continuing to thread, I came to the conclusion that the lack of constraints of the TC2 due to its single-end control, manual weft insert, non-repeating warp etc. means I have nothing tangible to work with - anything could happen with this loom!
>
> (Piper 2016: Journal Excerpt)

3.3.4 Re-establishing the Boundaries of Design and Construction

A review of the constraints still present when using and designing for the TC2 (prompted by the experience of threading the loom (Section 3.3.3) was conducted to re-establish the process boundaries for the research practice. This resulted in the identification of two types of parameters that apply to all forms of weaving (hand, digital and hybrid) – 'process parameters' and 'self-imposed parameters ' (Journal Excerpt 3.2).

> There still remains a fullness of choice but one not as overwhelming as that offered by unlimited opportunities. These boundaries may be conceived as the skeleton of a structure.
>
> (Albers 2000: 8)

Process parameters are those that are inherent in the process of weaving and in the materials being used. Self-imposed parameters derive from the overarching aims of the research in relation to functionality, sustainability and design aesthetics. These parameters are outlined in Table 3.3.

Parameter Type	Specific Parameter
Process Parameter	• Rectangular nature of woven fabric construction • Biaxial construction – horizontal and vertical insertion and intersection of yarns • Active yarns (when used in the warp) being continuous in the cloth even when shaping and movement is not required • Limitations of yarn use and structure combinations imposed by the individual loom • Predetermined type and colour of warp yarns (only applicable to Jacquard power loom and TC2)
Self-imposed	• Fabric and garment functionality (fit, comfort, durability and wearability) • Functional aesthetic (patterns with purpose, the influence of the body and the influence of the mode of construction) • Sustainability principles and methods (minimization/ elimination of waste, reducing material production and consumption, mono-materiality and pattern/component tessellation)

Table 3.3: Design and Construction Parameters

The process parameters placed restrictions on experimentation (e.g. yarn use, weave structure combinations) and garment design/possibilities, and informed which type of loom would be selected for the production of a particular garment prototype. Loom selection was based on the anticipated dimensions and envisaged complexity of the garment being developed, as well as the type, thickness and density of the yarns required to produce a textile appropriate for a particular garment application (t-shirt, jacket, trouser etc.). Once the mode of production was selected, the garment was designed to suit the particular loom's specifications.

The self-imposed parameters allowed me to retain control of the creative process through informed and directed decision-making. In particular, the established functionality and sustainability principles (seen in Table 3.3 above) provided clear design boundaries that regulated material selection and use, garment styling and aesthetics. The TC2 removed many of the process parameters, or at least changed them, so self-imposed parameters provided additional limits and control to retain a rigorous structure and focus in the design process.

3.4 The Role of Reflective Practice: Approaches and Application

This section outlines the approaches employed to capture, analyse and review technical and design processes and outcomes, as well as describing their evolution throughout the phases of the project. It begins by contextualising Action Research as a Practice-led Research methodology (Section 3.4.1), before discussing the two principal models on which the reflective methods were based – McNiff's Action Research Cycle (2013; 2002) and Schön's "Reflection in Action" and "Reflection on Action" (1991) (Section 3.4.2).

3.4.1 Practice-led Research: Action Research

Action research is a form of practice-led research, where continuous reflection on practice informs subsequent actions and the development/refinement of methods. It is an evolutionary and responsive process involving systematic investigation and self-evaluation (McNiff 2002). Originating in the social sciences and employed in "professional education" (Ibid) it has since been employed and adopted in other fields, including design and craft research (see Bang 2010; Wood 2006).

According to Swann, action research is an "established methodology for documentation" (2002: 58) with a rigorous approach to documentation involving a cyclical process of "group discussion, trialling of ideas, reflection, evaluation, and action in an iterative, evolutionary design process." (Ibid). He states: "Action research is an appropriate methodology for any project where the final outcome is undefined." (Ibid), as questions, methods and outcomes evolve in response to the critical analysis of prior action(s), following cycles of planning, acting, observing and reflecting (McNiff 2013: 57) (Section 3.4.2).

> Action research provides enough flexibility to allow fuzzy beginning while progressing towards appropriate endings […] a cyclical process is important. It gives more chances to learn from experience provided that there is real reflection on the process and on the outcomes, intended and unintended.
>
> (Dick 2000)

Whilst Swann (2002) and McNiff (2013; 2002) place particular emphasis on the collaborative nature of action research, Dick recognises differing levels of participation whereby "Participation may be limited to being involved as an informant." (2000). Trullen and Torbert go further, specifying a particular form of action research - "first-person research" (2013) – research by the individual into their own practice.

> By becoming "action researchers" of our own experience, we can go beyond our deeply ingrained defense mechanisms to create new possibilities for action.
>
> (Ibid)

This individual or "first-person" approach does not preclude the involvement of others, indeed McNiff, Lomax and Whitehead express the need for "peer-validation" to achieve "unprejudiced" critique of actions, decisions, outcomes and findings (2003: 25). Validation is deemed to be an integral part of critical self-reflexive practice, it involves feedback from informed individuals – tutors, mentors, co-practitioners, colleagues and participants – to challenge thinking (Ibid: 29).

> Validity is established by showing how interpretations of experience can be negotiated by different people.
>
> (Ibid)

Principally, the process of action research is the cyclical development of both understanding and practice that is grounded in experience; involving heightened awareness of action, practice and purpose (Reason & Bradbury 2001), and achieved through rigorous documentation of action and reflection, with the evolution of research methods in response to the practice and process.

3.4.2 Action Research: Action / Capture / Analyse / Review

"Reflection in Action" (Schön 1991) intuitively occurs during making as decisions are made, problems are solved, and ideas evolve in response to engagement with the process, drawing (both consciously and unconsciously) from technical principles and experiential knowledge. However, active (or conscious) reflection during making, and the recording of this reflection, can disrupt the flow of activity. By drawing attention to individual actions, the process becomes fragmented, and the natural embodied responses to material, tools and process may fail (Journal Excerpt 3.3). The maker becomes self-conscious: the flow, the movement, the sense and bodily response is lost, and the process breaks down. (O'Connor 2007; Csikzentmihalyi & Csikzentmihalyi Eds. 1988; Dreyfus & Dreyfus 1986).

> [...] a reading of the practice cannot be an operative principle of proficiency, as it calls for an interruption of practice, in virtue of the abstraction and reflection it requires.
>
> (O'Connor 2007: 137)

Nevertheless, as in this practice based investigation, self-reflection is central to action research. It involves systematic investigation, developmental processes, the following through of ideas, and self-evaluation. McNiff (2002) refers to it as an evolutionary process involving the solving of a problem by identifying a solution, testing it and subsequently evaluating it. McNiff's Action Research Cycle (Figure 3.6) illustrates a systematic cyclical process of reflection.

> Two processes are at work: your systematic actions as you work your way through these steps, and your learning. Your actions embody your learning, and your learning is informed by your reflections on your actions.
>
> (McNiff 2002: 11)

My research reinterprets the Action Research Cycle - Plan, Act, Observe and Reflect (McNiff 2013: 56) - as ongoing phases of Action/Capture/Analysis/Review; a process that embeds "Reflection in Action" and "Reflection on Action" (Schön 1991) as continuous activities. Working in this way, I (the designer/researcher) fulfil "multiple

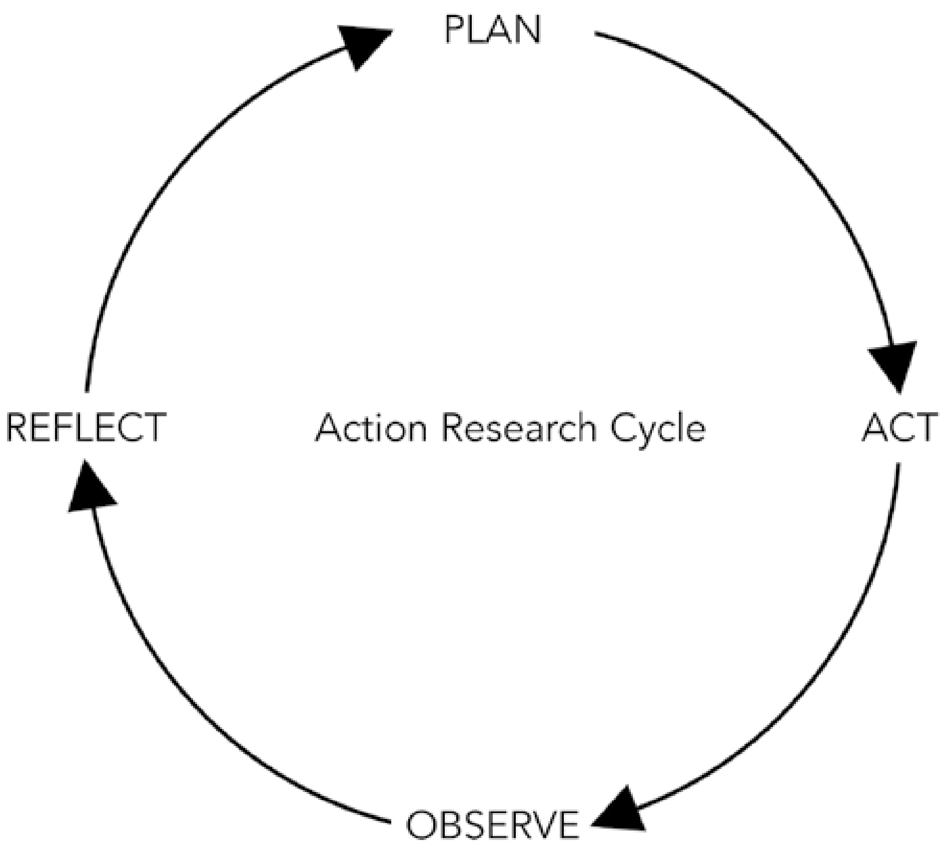


Figure 3.6: Action Research Cycle (2015)
Illustration by Anna Piper Based on Diagram by McNiff (2002)

roles of self-observer, self-analyst and self-reporter" (Pedgley 2007: 464), facilitated by the application of multiple reflective and recording methods (Sections 3.4.3 and 3.4.4).

3.4.3 Reflective Methods: Identified Approaches

Aligned with the ongoing reflective phases of Action/Capture/Analysis/Review, a range of reflective methods were identified to enable questioning, deconstruction and restructuring of practice, as well as to facilitate conceptual thinking, knowledge transfer and innovation through heightened awareness and advanced knowledge (technical and experiential) of practitioner, process and the made object (Section 3.6.1). In addition, the research required the "triangulation" (Gray & Malins 2004: 31) of the three interrelated elements of sustainable design, technical process (encompassing technical functionality and design aesthetics) and embodied knowledge (2.3.1), all of which were considered in parallel (Lawson 2006) throughout the research phases to facilitate an informative 'conversation' between each (Figure 3.7).

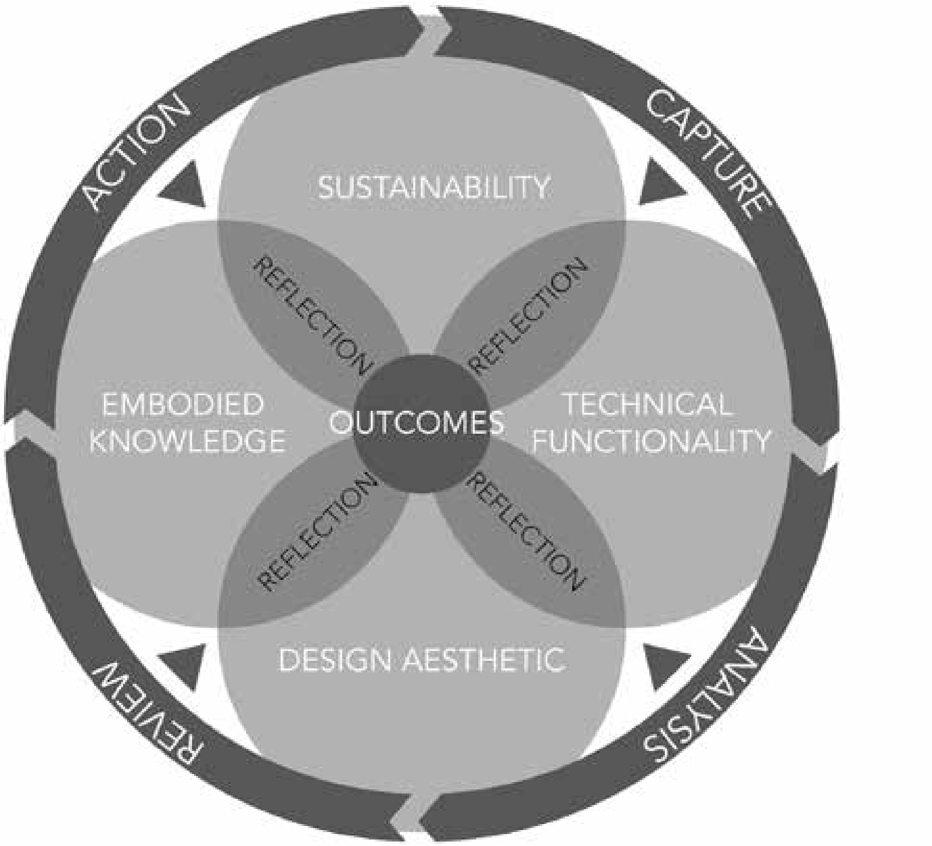


Figure 3.7: Action / Capture / Analysis / Review Process (2014)
Illustration by Anna Piper

Action: due to the complexities of integrating textile and garment design and construction, as well as the technicalities of developing integral textile shaping techniques, two 'action' phases were identified – Component Construction (focusing on technical technique development) and Garment Construction (the application of Component Construction outcomes to produce garment prototypes) (Chapter 7).

Capture: inspired by Adamson's "Craft only exists in motion" (2007: 4), film recording was selected as an analytical device to record intuitive actions and material engagements (Philpott 2012), to understand process and techniques and to capture retrospectively significant events (Wood 2006). These film-based 'Action Records' were to be supported by comprehensive written records to document and reflect on action, in order to examine and advance practice. In addition, previously successful recording methods - sketchbook annotation, note-taking and photography to capture key design decisions and iterations – were applied.

Analysis: 'Action Records', along with technical construction documentation, were identified as integral in the analysis of the practitioner and practical outcomes (Section 3.5); providing data for "reconsidering the structure of working processes" (Lehmann, U 2012: 153) and "analysis of existing *techne*" (Ibid) to inform and facilitate the advancement of design, process and construction. Analysis was scheduled to take place at the end of each cycle of design and making activity, with samples to be individually and collectively analysed following the completion of sampling on a particular warp and garment designs evaluated at each development stage.

Review: systematic and formal review throughout the research process, in the form of a Design Review Protocol (Schön 1991), was designed to facilitate the application of new knowledge and understanding in subsequent 'Action Phases', resulting in continuous challenge and the advancement of practical weaving skills. Schön's (1991) Design Review Protocol (a design tutorial process to facilitate student reflection to frame "new appreciations and understanding" (Ibid: 79)) was adapted as a reflective tool to review construction phases (see Appendix 1 for Design Review Protocols). The protocol promotes comparative selection and decision-making, whereby relational (rather than linear) reflection takes place (McNiff 2013: 27), considering the wider functionality, sustainability and aesthetic implications of the research.

Table 3.4 provides the detail of each individual method aligned with the relevant reflective stage. When applied, this systematic multi-method approach was found to be overly dogmatic, time consuming and, at times, repetitive. Methods were therefore reviewed and adapted throughout the research (Sections 3.4.4).

3.4.4 Component Construction Phase: Reflective Method Selection and Use

Table 3.4 outlines the reflective methods applied during the Component Construction phase of the research, along with their intended purpose. With the exception of filming the weaving process, all methods were employed throughout this research phase.

Having undertaken a number of stages of technical sampling, a review of blog entries and film records was conducted. This revealed that film recording did little to advance the knowledge or understanding of process, technique and material engagements, already derived and captured through the reflective journal (seen in Journal Excerpt

Method	Intended Purpose	Component Construction	Garment Construction	Use/Application (if different from intended purpose)
Blog-based journal	• To document and reflect on action, and to examine and advance practice • To enable questioning, deconstruction and reconstruction of practice	✓	✓	Garment Construction Phase • To consider the wider functionality, sustainability and aesthetic implications of the research • Comparative selection and decision-making
Design review	• To review construction phases, for comparative selection and decision-making • To consider the wider functionality, sustainability and aesthetic implications of the research	✓		
Filming	• Employed as an analytical tool to capture intuitive actions and material engagements • To understand process and technique	✓	✓	Component and Garment Construction Phases • To record the making process to communicate concept and its complexities
Photography	• To record the making process to communicate concept and its complexities • To assist in the communication of implicit and explicit knowledge • To document and record garment development, for design and process analysis	✓	✓	• To assist in the communication of implicit and explicit knowledge
Sketchbook Note-taking	• To document garment design and development		✓	
	• To document design ideas, development and decision making	✓	✓	

Table 3.4: Reflective Methods and Application

3.4) and the initial review of MA practice (Section 3.3.1). It does, however, provide a valuable source of visual imagery to convey the concept of CPW and its complexities (Section 2.7); as well as assisting in the communication of implicit and explicit knowledge (Section 2.3). In response to this finding, the volume of filming was reduced in the final stages of technical sampling and used only to supplement photographic records during the production of garment prototypes in the Garment Construction phase.

3.4.5 Garment Construction Phase: Reflective Method Selection and Use

Table 3.4 also details the reflective methods used, and their intended purpose and application in the Garment Construction phase of the project. The reflective methods employed during Component Construction were initially employed in the Garment Construction phase, however, it quickly became evident that the Design Review Protocol was a duplication of the recording taking place during the action of designing (captured in sketchbook annotation) and the reflection on action being captured in the reflective blog (Journal Excerpt 3.5). As a result, the Design Review Protocol was abandoned during this phase of the research.

This highlighted the necessity for reframing action research as the practice evolved, and the evolution of Action/Capture/Analysis/Review (illustrated in Table 3.5) within the phases of development to suit the differing demands of technical textile sampling and fashion design/garment development.

3.5 The Role of Technical Records: Analysis and Documentation

Lehmann (2012) asserts that analysis of existing *techne* (craftsmanship/making) can lead to innovations in practice and the episteme (knowing/true knowledge), whilst Malafouris' 'Extended Mind Theory' (2013) stresses that knowledge of the mind can be derived by understanding the physical object. This section details the criteria and methods used for analysing technical and design outcomes in both the Component and Garment Construction phases of the research. It highlights the vital role that object (or outcome) analysis and technical documentation play in the advancement of practice, enabling the creativity and innovation which is intrinsic to the Transitional Design Methodology.

	Component Construction	Garment Construction
Action	• Planned actions based on the application of technical knowledge of weave structures, yarns and construction derived from established practice and theoretical research. • Testing and development within a single period of weaving, whereby multiple techniques, structures and yarns were explored/applied on a single warp.	• Design of pre-defined garment type(s) (top, dress, jacket…) on paper/on screen, working with pre-determined constraints of production – width of cloth and its rectangular nature and minimisation of waste. • Development of paper/screen-based design in fabric and on the mannequin based on constraints above, as well as criteria relating to functionality of textile and garment, and developed shaping techniques.
Analysis	• Systematic post-production analysis of individual textile outcomes, based on pre-established criteria relating to the specified aims and constraints of the research.	• Responsive and intuitive analysis of design aesthetic, fit and technical process during action, feeding into subsequent actions and parallel designs. • Direct analysis of designs post-action, considering constraints of the CPW concept, modes of construction, technology (software), and sustainability and functionality aims.
Review	• Comparative review of past and current textile outcomes to identify the most successful techniques for application to garments and prioritise future sampling, experimentation and action.	• Objective review of ideas, opportunities and designs for individual prototypes and the collection as a whole based on the specified aims and constraints of the research, to inform development/adaptation of existing and future designs and to establish next steps.

Table 3.5: Evolution of Action Research: Action, Analysis and Review

3.5.1 Component Construction: Sampling Approach and Evaluation

The Component Construction phase of the research concentrated on the development and selection of yarns and weave structure combinations for integral shaping of fabrics. Using a systematic approach to sampling, with structures and yarns tested with a single variable in each sample; the impact on the fabric structure, handle and appearance, along with the 'activity' of the yarn (its movement within the fabric construction) was evaluated. Potential applications were also identified based on these characteristics, type of shaping and basic aesthetic qualities (Sections 7.3.1 and 7.3.2).

Individual 'Yarn Data Sheets' were produced for each yarn used; recording sample findings, activity data and use potential, along with yarn specification (count, twist, colour etc.) and properties (Figure 3.8). At this stage in the research, yarn colour and introduction of pattern (other than that achieved, as a result of the technique(s) used) was not a consideration.

A broad range of yarn types were tested, in different combinations with multiple weave structures. This allowed a range of techniques to be explored and facilitated the elimination of both techniques and specific yarns. The composition and construction of each sample was recorded in detail (see Figure 3.9), and analysed in detail using the following criteria:

Overall effect: taking into consideration yarn and structure combination, quality of construction, and intended shaping effect.

Handle: assessing fabric weight, stability, movement, strength, consistency and suitability for garment application.

Appearance: considering aesthetic qualities relating to weave structure, pattern, density, scale and colour (where applicable).

Use potential: possible applications within garment construction based on fabric type, handle, shaping ability and appearance.

Further development: identifying improvements and/or changes to structures, yarn combinations and density to achieve the desired effect and to enhance shaping, handle and aesthetics. Techniques and yarn combinations were also rejected at this stage.

Yarn Data Sheet

Shrink Polyester

Category: Active | Synthetic | Shrink

Yarn Specification

Count: 60/2nm
Twist: S
Colour(s): White
Source: Handweavers Studio

Basic Weave Specification

Ends per inch: 40
Picks per inch: 40
Use: Weft*
Loom suitability: All **

Properties

Appearance: smooth | shiny | compact | fine | clean
Handle: smooth | soft | light | good drape | stable
Use Potential: permanent shrink & shape | corded pleating | seersucker | clasped weft panelling | ribbing

Activity Specification

Average shrink (%): 22% (see findings)
Average extension (%): 0%

Findings

1. Provides permanent shrink, with the shrinking being consistent across the length of the yarn rather than controlled by changes in weave structure within the cloth. This results in an increased density in the warp direction.
2. 22% shrinkage consistently achieved when yarn is used with plain weave, 27 Tex Polyester warp (36 EPI) and weft. The level of shrinkage is not affected by the ratio of active weft to passive weft, or by application across the full width of the cloth or in shaped panels.
3. The level of shrinkage is reduced by an increased warp and weft thickness. Note: the type of yarn is a variable (using 2/16 Mercerised Cotton warp (28 EPI).
4. Tests that combine the yarn with 3/1 & 1/3 twills and 3/1 & plain weave blocks are inconclusive and require further testing as shrinkage levels cannot be predicted from current data.
5. Successful pleating can be achieved combining the yarn with a corded pleat structure; however, the levels of shrinkage are difficult to accurately measure due to the form/folding created and the number of variables in the individual samples completed at this stage.

Comments/Notes

1. Testing of 3D folding undertaken based on corded pleat principles. Initial tests were unsuccessful with testing abandoned in favour of an alternative technique (Shibori).

Selected for use: Yes

*Yarn only used in the weft but is suitable and strong enough for use in the warp.
** The shiny slippery nature of the yarn means that when used on the Jacquard a core yarn is required.

Activity Data

Structure	Plain	Plain	Plain & Extra Weft	Plain & Corded Pleat
Shrink (%)	22.5%	22.5%	25%	17%
Warp Yarn	27 Tex Polyester	27 Tex Polyester	27 Tex Polyester	50s Linen
Additional Weft	60/2 Silk (alternate)	None	27 Tex Polyester (2x2)	27 Tex Polyester (2x2)
Warp Sett	36	36	36	32
Finishing	Steam	Steam	Steam	Steam

Structure	Plain & Corded Pleat	Plain & Corded Pleat	Plain & Corded Pleat	Plain & Corded Pleat
Shrink (%)	23%	23%	26%	20%
Warp Yarn	50s Linen	27 Tex Polyester	27 Tex Polyester	50s Linen
Additional Weft	50s Linen (2x2)	27 Tex Polyester (2x2)	50s Linen (2x2)	2/16 Cotton (2x2)
Warp Sett	32	44	32	32
Finishing	Steam	Steam	Steam	Steam

Structure	Plain & Corded Pleat	Plain	Plain	Plain
Shrink (%)	24%	12%	14%	17%
Warp Yarn	27 Tex Polyester	2/16ne Cotton & 60/2 Silk (bundled)	2/16ne Cotton & 9.6/2nm Linen (bundled)	2/16ne Cotton
Additional Weft	2/16ne Cotton (2x2)	2/16ne Cotton (3x1)	2/16ne Cotton (3x1)	2/16ne Cotton (3x1)
Warp Sett	44	28	28	28
Finishing	Steam	Steam	Steam	Steam

Structure	3/1 & 1/3 Twill Blocks	3/1 & Plain Blocks	3/1 & 1/3 Twill Blocks	Plain
Shrink (%)	19%	16%	25%	22%
Warp Yarn	2/16ne Cotton	2/16ne Cotton	2/16ne Cotton	27 Tex Polyester
Additional Weft	2/16ne Cotton (Alternate)	2/16ne Cotton (Alternate)	2/16ne Cotton (Alternate) & lower section 2/16 Cotton	27 Tex Polyester (3 x 1)
Warp Sett	28	28	28	36
Finishing	Steam	Steam	Steam	Steam

Structure	Plain	Plain	Plain Weave Clasped Weft	Plain Weave Clasped Weft
Shrink (%)	22%	22%	Results invalid	22%
Warp Yarn	27 Tex Polyester	27 Tex Polyester	27 Tex Polyester	27 Tex Polyester
Additional Weft	27 Tex Polyester (5 x 1)	27 Tex Polyester (7 x 1)	27 Tex Polyester (4x1)	27 Tex Polyester (inserted together)
Warp Sett	36	36	36	36
Finishing	Steam	Steam	Steam	Steam

Figure 3.8: Yarn Data Sheet Example (2014)

Technical Sampling: W2P1S9

•	**Warp Yarn(s):**	27 Tex Polyester (black)			**Handle**
•	**Weft Yarn(s):**	2/16ne Mercerised Cotton (Grey) & 14.5nm		•	The handle of this fabric is much the same as the previous sample - soft with
		High Twist Merino (ecru)			a fluffy slightly felted surface. Although there is some roughness where the
•	**PPI:**	Approx. 32			floats are slightly raised there is some added roughness.
•	**Weave Structure(s):**	Box Cord Pleat (plain with floats)		•	There is some stretch and give evident when the sample is pulled in the
•	**Pre-finished Dimensions:**	Finished without measuring in error			weft direction.
					The combination of cotton and wool (slightly thicker than the other
•	**Finishing:**	Machine Wash - Wool Cycle - 40 - 800 spin			combinations) gives a thicker, slightly bulkier handle and weight. This is not
•	**Post-finishing Dimensions**	W9.75" x H6.5"			detrimental in terms of a flat cloth, but may mean that any pleats would not
					be as sharp - I have chosen not to press the pleats into this sample, as there
					was not sufficient yarn manipulation to create a self-fold, or close to a
	Overall Effect				self-fold effect.
•	The outcome of this sample is half way between the two previous				
	samples - there is some shrinking and felting of the wool, with some				**Use Potential**
	minor manipulation and movement in the floated sections.			•	The effects of the previous two samples - one in terms of shrink, and the
•	The movement in the floats is sufficient to force the base cloth slightly				other in terms of pleating - are superior to the effects generated here. As
	forwards and backwards.				such this yarn combination will not be pursued any further.
•	There is some disruption in the base cloth, with some evidence of				
	tracking				**Appearance**
				•	The combination of silver and ecru results in a very subtle stripe that is
					diffused by the fibres and softness of the wool.
				•	Again the fabric appears textural, with some unevenness and fluidity both in
					the base cloth and in the vertical stripes of floats - these stripes/floats are in
					fact a little untidy.

Figure 3.9: Technical Sample Analysis Example (2014)

These criteria were based on functionality and were intended to assess the suitability of the sampling outcomes for application to garments. Whilst aesthetic qualities were recorded, at this stage of the research they were not a priority, as garment designs would evolve in response to the shaping/fitting capabilities and associated aesthetic characteristics of the successful techniques.

Following the individual sample analysis (described above), further comparative analysis took place. Applying and adapting Schön's (1991) Design Review Protocol, techniques were evaluated, compared and selected, whilst considering wider implications for functionality, sustainability, aesthetics and application (see Appendix 1 for full Design Review Records). Selection and decision-making, therefore, took place with the production of each batch of samples, to allow construction and methods to be refined and eliminated incrementally. See Section 7.3 for sampling outcomes and technique selection.

3.5.2 Garment Construction: Design and Process Analysis

The Garment Construction phase of the research applied the weave structures and yarns identified in the Component Construction phase to the construction of six garment prototypes – a long-sleeved top, t-shirt, dress, jacket, trousers and coat. Rather than each garment being designed in isolation, multiple garments were worked on in parallel rather than in a linear sequence, to allow design ideas, construction techniques and design analysis to be shared and applied across multiple prototypes.

The starting points for each design were the intended mode of construction and loom type, along with the associated maximum fabric/warp width (Section 7.2)[3]. Each garment then went through a process of physical and digital lay-plan design, pattern making, toile construction and weaving. The composite patterns (or lay-plans) to be produced using digital or hybrid looms were also converted to a digital format using Pointcarre weave software. Each design went through a series of iterations and was incrementally altered and refined through ongoing reflection and analysis at each stage. Designs were evaluated during this process using sketchbook and pattern annotation (Figure 3.10),

[3] In the case of digital and hybrid production the warp width and type are fixed. The hand loom, whilst having a maximum warp width, provides scope for altering the width of the warp to suit the garment design; the design itself determines warp threading, width and yarn type.

Figure 3.10: Sketchbook Design Analysis and Annotation: T-shirt Toile Version #1 (2018)
Photograph by Anna Piper

with each pattern, toile and prototype retained for reference, and photographs taken at critical decision-making stages. Detailed records of the design and construction of each garment prototype can be seen in Chapter 7. Appendix 2 provides an overview of the Pointcarre weave software alongwith full details of the digital pattern conversion process.

Analysis, evaluation and decision making was based on the following principles and criteria:

Overall aesthetic:	taking into consideration design and construction quality, as well as styling, to achieve a balance between functional performance, aesthetic impact and wearability.
Shaping:	assessing the suitability of shaping techniques to achieve the desired fit, style and garment functionality (i.e. facilitation of movement and temperature regulation).
Panelling and pattern placement:	considering the stylistic qualities of the garment design including scale, balance, proportion and colour application to achieve the intended sports fashion aesthetic and garment functionality.
Fabric composition:	assessing fabric weight, drape, movement, consistency, wearability and durability, whilst also striving to limit the number of fibre types utilised to take into account future recyclability; with the ideal being to produce single-fibre garments.
Waste elimination:	reviewing the designs to ensure adherence to ZWPC principles, and the best possible utilisation of fabric to contribute to the garment's overall functionality.

The key factors driving this evaluation and decision-making were aligned with the sustainability and functionality aims of the research (Chapters 5 and 6) to achieve the best possible balance between these elements to allow the garments to perform both functionally and aesthetically. In addition, design decisions were made to achieve the technical aim of the research (Section 4.1) – to demonstrate the viability and flexibility of this type of pattern design and garment construction, by using multiple shaping techniques in different ways, as well as applying multiple weave construction methods (hand, digital and hybrid weaving).

3.6 Parallel Thinking and Making

> To realize innovation, we need to break the fixed pattern of thinking and achieve our objectives by doing more than simply changing appearances.
>
> (Jiang 2009: 46)

This research challenges and presents an alternative to the established linear approaches to the integration of analogue and digital production (Section 2.5). Applying an iterative transitional methodology, with hand and digital weaving development taking place in parallel, to capitalise on the constraints and affordances of the two modes of design conceptualisation and construction (Section 7.2). Hand processes provide a platform for digital development, but equally, digital construction informs innovation in hand production. The assimilation of textile and fashion design, construction and methods within the practice add a further level of manual/digital integration (Section 3.6.2), as well as introducing additional complexity, uncertainty, risk and potential for innovation.

3.6.1 Parallel Approaches: Cross-disciplinary Transfer

In describing the transfer of techniques from one discipline to another, Lehmann states "transfer heightens the awareness of structural differences that reach far beyond the traditional exercise of craft itself." (2012: 155), so he advocates "reconsidering the structure of working processes" (Ibid: 153) as a platform for innovation and conceptual thinking. Successfully challenging current thinking and generating new knowledge demands a departure from prescribed rules and established traditions; which may involve deconstructing or reversing existing '*techne*', or the transfer and application of methods, skills or materials from other disciplines.

Lawson (2006) suggests that effective design involves multiple co-existing lines of thought. He states, "good designers are able to sustain several 'conversations'[...] without worrying that the whole does not yet make sense." (Ibid: 219). These "parallel lines of thought" (Ibid) may contradict and conflict, but they allow for multifaceted and simultaneous thinking about different aspects (or components) of a design. Gwilt applies Lawson's theory to sustainable fashion design, advocating an organisational rather than a linear supply chain model, with the designer at the core of an integrated process, allowing them to "design, plan and create a new garment design in tandem with the integration of sustainable strategies." (Gwilt 2011: 69).

In this research, a number of elements operate in parallel. The multi-method lifecycle approach to design responsibility and sustainability (outlined in Section 5.3) - a central pillar of the CPW concept - influences textile composition and construction as well as garment design and production, and as such, it underpins all design decisions. Furthermore, the simultaneous design and construction of textile and garment in CPW requires equal emphasis to be placed on each interdependent element throughout the design process. Concurrency between textile, fashion and sustainable design is therefore intrinsic to the success of the garment outcomes.

3.6.2 Parallel Approaches: Integration of Textile and Fashion Practice

In CPW, multiple textile and fashion processes take place in parallel, requiring a combination of experimentation, open-mindedness and embodied knowledge in order to understand the potential of materials, processes and modes of production (Section 2.8), and to exploit the opportunities of simultaneous textile and fashion construction. Weaving practice incorporates technical testing of materials and structures, experimental sampling for fabric development (focusing on design aesthetics) and prototyping of garment shapes and details. Textile processes do not take place in isolation; modelling on the garment stand, toileing, the construction of paper patterns and experimentation with fabric samples on the mannequin and body, are all required to inform the style, construction and the interrelationship between the fabric, garment and body.

In hand weaving, the warp (its design and threading) is developed from the pattern and garment design in conjunction with the chosen fabric design and selected yarns. The digital and hybrid production process incorporates the conversion of the physical lay-plan into a digital image, providing the base data for programming upon which weave structures are applied (Figure 3.11) - a process that unites conventional analogue fashion (pattern making) techniques with digital programming for woven construction. The processes are described and illustrated in detail in Chapter 7.

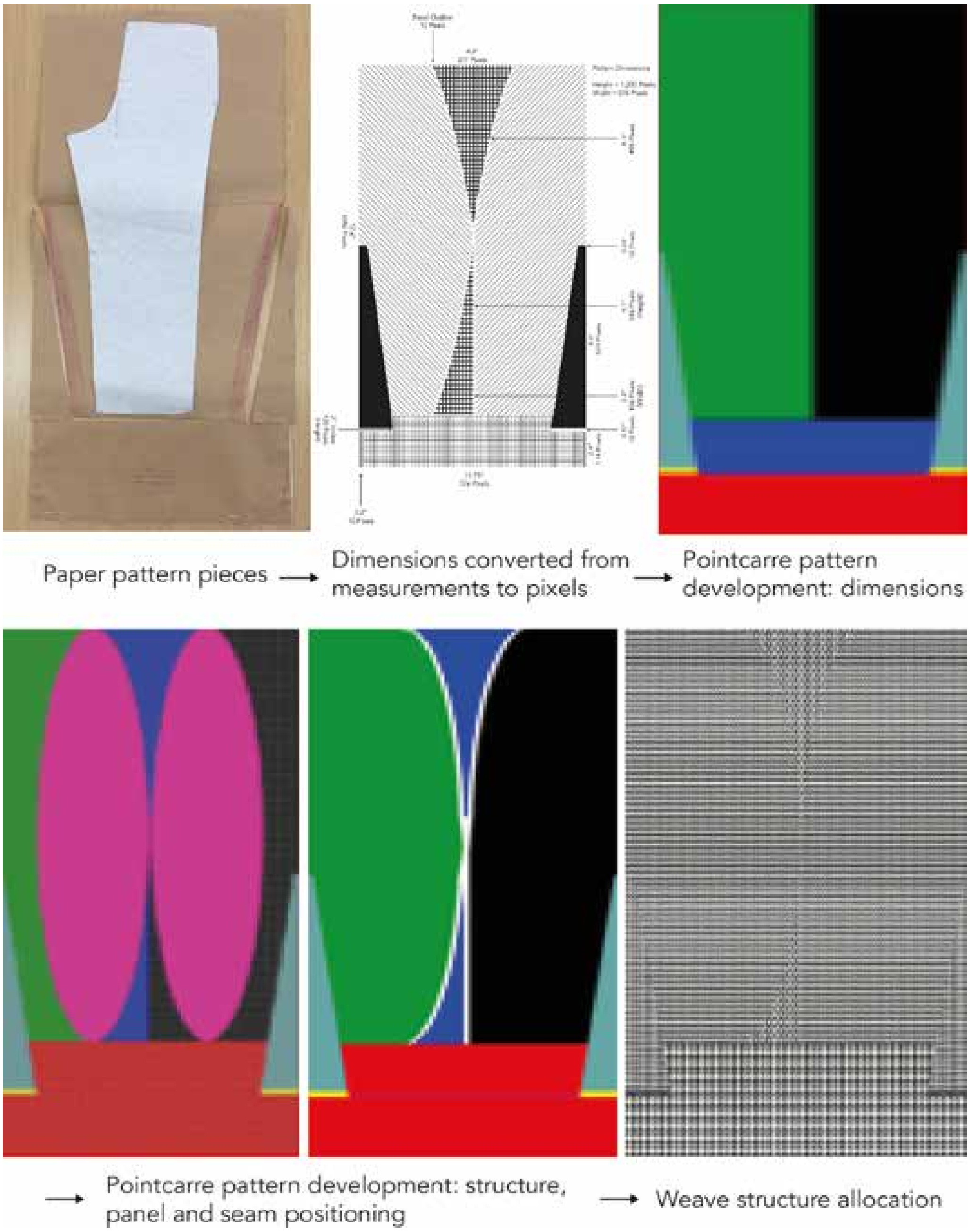


Figure 3.11: Pattern Digitisation Process: Jacquard Woven Trousers (2018)
Illustration by Anna Piper

3.7 Heuristic Approaches: Zero Waste Pattern Cutting and Whole Garment Knitting Practice

For creative practitioners, engaging in practice provides the freedom to learn through experimentation and to challenge conventional ways of working and thinking by testing the limits and possibilities of materials and processes (Section 2.3.2). As such, creative practice has an affinity with heuristic inquiry; rather than relying on "theoretical first principles" (Lawson 2006: 185) they both depend on 'learning through doing' (Section 2.3.1). Heuristic inquiry is concerned with the lived experience of a researcher, aiming to expand knowledge through exploration and interpretation of experience, self-dialogue, self-reflection and intuition (Hiles 2001). It involves systematic observation and experimentation leading to discovery (Kleining & Witt 2000).

This research adopts this heuristic approach to design, drawing from a range of disciplines and practices, borrowing, adapting and combining methods from zero waste pattern cutting (ZWPC) and whole garment knitting to stimulate new ways of working and thinking about woven garment design and construction through the integration of sustainable practice.

3.7.1 Practice-led Research: Heuristic Thinking

Abbot describes Heuristics as the study of "how to find things out" (2004: 80) by using an experimental (or explorative) approach to find solutions by thinking creatively – stimulating thinking by thinking "more broadly than is customary" (Ibid: 107).

> It is by freeing oneself from the conventional association of certain objects of analysis with certain kinds of methods that one opens oneself to the rich possibilities of borrowing.
>
> (Ibid: 120)

Abbott outlines two forms of Heuristics – Search Heuristics and Argument Heuristics – both are designed to instigate new ways of thinking. The latter advocates questioning assumptions, reversing a problem and reconceptualising the idea to reframe the argument. The former involves borrowing and applying methods from elsewhere to initiate new approaches, to change thinking and to challenge conventions (Ibid: 110-134). This acquisition of methods from elsewhere and reframing of a problem, supports Lehmann's theory that:

> [...] only a deliberate departure [from traditional modes of practice] allows for genuinely new knowledge to be generated […] Conversely, innovation can be a reversal of existing processes to critique established traditions […] This involves reconsidering the structure of working processes as a basis for design innovation.
>
> (2012: 151)

3.7.2 Heuristic Design Approach: Transition Design

> […] new ways of designing need to be informed by knowledge outside design (science, philosophy, psychology, social science, anthropology, and the humanities etc.) in order to gain a deeper understanding of how to design for change/transition in complex systems.
>
> (Irwin, Kossoff & Tonkinwise 2015: 4)

Transition Design recognises the meaningful role that design, and designers can have in finding solutions to societal and global "wicked problems" (Irwin 2015) that arise from "multiple root causes" (Irwin, Tonkinwise & Kossoff 2015), including climate change and the economic disparity between rich and poor. The emerging Transition Design framework complements existing (but relatively new) Design for Service and Design for Innovation approaches, by focussing on design-led solutions that:

> […] have their origins in long-term thinking, are lifestyle-oriented and place-based, and always acknowledge the natural world as the greater context for all design solutions.
>
> (Irwin 2015: 231)

Social, political and natural systems are seen as interconnected, with a transition to a more socially and environmentally sustainable future requiring the development of new visions, knowledge, theories, mindsets and ways of designing that challenge the existing (unsustainable) socio-economic and political models. Transition Design advocates a move from "linear, cause-and-effect thinking" (Ibid: 234) to an open, cyclical, iterative and evolutionary approach (Irwin 2015; Irwin, Kossoff & Tonkinwise 2015), involving self-reflection[4], cross-disciplinary knowledge, interaction and collaboration (Irwin 2015: 236) as well as a commitment to personal and system change (Ibid: 237).

---

[4] Irwin describes Transition Design as involving the examination of a designer's personal "values system and the role it plays in the design process" (2015: 235), to foster new understanding, attitudes and approaches which are "informed by different value sets and knowledge" (Ibid: 236).

Transition Design and the Transitional Design Methodology share a heuristic and evolutionary approach to sustainable design, whereby interconnectedness, cross-disciplinary transfer (of knowledge, understanding and experience) and self-reflection facilitate the development of ideas and innovation. Despite these apparent connections and the similarity in the naming of the two approaches, it is important to note that the Transitional Design Methodology and the Transition Design framework, whilst complementary, have developed concurrently and independently.

3.7.3 Heuristic Design Approach: Zero Waste Pattern Cutting

There are a number of methods associated with ZWPC (Section 5.7), however, the over-arching principle is the creation of a pattern that uses 100% of a piece of fabric. The objective of ZWPC is (generally) not to minimise material consumption but to eliminate waste. In this process, the fabric width is dictated, but the length of the cloth is determined by the design process (Rissanen 2013). This form of pattern cutting is considered to be a design approach, or tool, that integrates both garment and pattern design. It involves intuition, the making of mistakes and risk-taking (Rissanen 2013; McQuillan 2010). Townsend and Mills (2012) consider ZWPC to be a creative framework within which new design methodologies can be developed.

ZWPC challenges the designer to re-evaluate the relationship between the garment and the body, and to re-examine the conventions of pattern cutting and garment construction. For designers such as Julian Roberts, the quality and success of the design is of critical importance and must be balanced with the ambition to eliminate waste.

> I personally think fabric waste needs to be weighed-up, and the aspiration to waste as little as possible become balanced, so that it does not eclipse other important design considerations. You have to be aware that a pattern which wastes 2% or 7% of fabric, may have the potential to be a 'better and more successful design' than a garment constructed to waste absolutely nothing. What's more important is the ambition to waste less and to think harder, and use the creative potential of Zero Waste to transform how you view a pattern in the first place.
>
> (Roberts 2014)

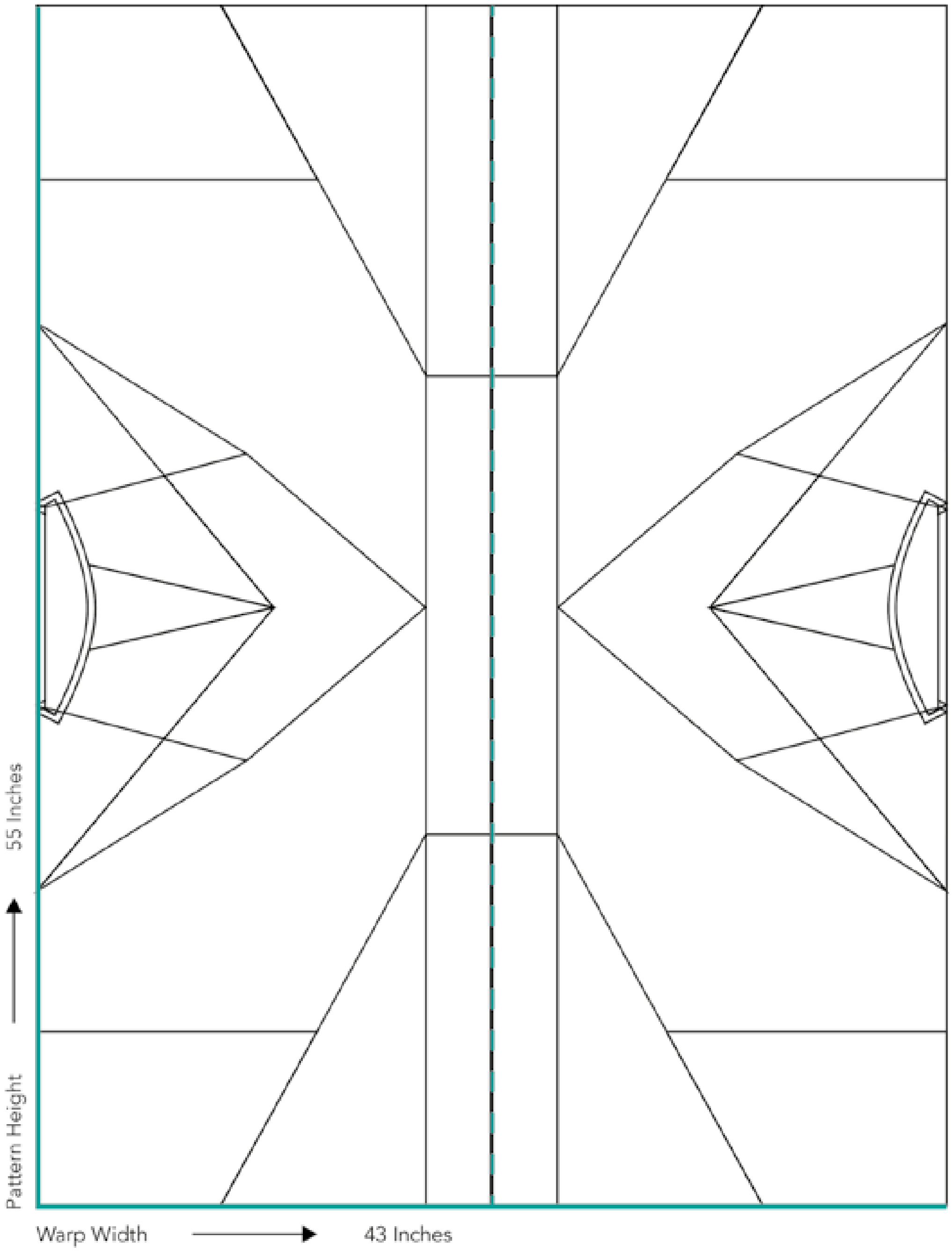


Figure 3.12: Garment Lay-plan with Pattern and Warp Dimensions (2016)
Illustration by Anna Piper

Whilst "Absolute Zero" (Ibid) (eliminating waste entirely) is the ultimate goal, reducing and minimising waste is also a positive outcome and can be a step towards reducing material consumption and waste production[5].

[5] Nike's Flyknit technology provides evidence of the significant impact the reduction of waste in a design can have when applied in commercial production. Flyknit construction reduces waste by 60% when compared to conventional cut and sew construction, and has resulted in a reduction of approximately 3.5 million pounds-worth of waste since 2012 (Nike 2016).

The process of ZWPC begins with the dimensional constraints of the cloth, rather than with the pattern block (Rissanen & McQuillan 2016). The rectangle and the maximum width of the warp (and therefore the maximum width of the cloth) is the starting point for a CPW design; the lay-plan must conform to (or fit into) the predetermined dimensions[6] (Figure 3.12). Unlike ZWPC, the transition from 2D fabric to 3D garment takes place, through a combination of traditional methods of stitching, seaming and tailoring, as well as the innovative integration of shape-manipulating fibres and weave structures embedded into the fabric construction. This holistic "simultaneous approach" (Townsend 2004a) challenges the hierarchical fashion system of designing, pattern making, lay-planning and cutting, by integrating "design and production" more naturally (McQuillan 2011: 85).

3.7.4 Heuristic Design Approach: Whole Garment Knitting

Whole knitted garments (WHOLEGARMENT ®[7]) are constructed in a single piece using integrated shaping, with minimal or no seams. Fully-fashioned knitwear also incorporates integrated shaping into garment components that are shaped on the knitting machine. A number of techniques are used in integral shaping: course and wale shaping, tubular knitting, changing stitch type and casting off (see Section 4.6.3 for further details on the various forms of knitted garment manufacture and associated shaping techniques). Integral shaping can produce darts, buttonholes, pleats and pockets. The combination of knit's inherent stretch, integral shaping and seamless construction enables the minimisation or elimination of cutting waste as well as minimising material production.

---

[6] When designing for the Jacquard power loom and the TC2 the predetermined warp widths govern the width of the lay-plan. However, when designing for the hand loom the maximum warp width (determined by the dimensions of the loom) defines the maximum width of the lay-plan but the lay-plan (and warp) can be designed to be narrower.

[7] WHOLEGARMENT ® knitwear technology by Shima Seiki allows a garment to be produced seamlessly on the knitting machine. It facilitates integral shaping and can eliminate sewing from the knitted garment production process. Since its introduction at the ITMA exposition in 1995, the technology has been applied to sports, medical and fashion garments (Shima Seiki c.2017; Taylor & Townsend 2014).

> Seamless knitting is a recognized form of zero waste design, the aim being for the garment to emerge from the machine with as little making-up or wasted fabric as possible. As knitwear naturally encompasses stretch, there is natural 'ease' built into the garment; but depending on the yarn and stitch structure this can be limited, and therefore the design still relies upon expertise in pattern cutting and construction techniques.
>
> (Taylor & Townsend 2014:165)

Similar to whole garment and fully-fashioned knitting, CPW integrates 3D shaping into the construction of the textile. The design of textile and garment is simultaneous, and as such the mode of production is the starting point (or tool) for design (Ibid: 167). The process demands extensive knowledge of material structure and fibre characteristics. It also requires the ability to envisage and digitally programme the design. It is not until the design is physically constructed that the design's success can be assessed, as the digital programme is not capable of predicting and simulating the effects of the structure and yarn combinations used to shape and manipulate the garment.

The commonalities between whole garment knitting and CPW, outlined above, mean that knitwear's well-established shaping techniques, construction processes and calculation methods provide a blueprint for woven garment design and production.

3.8 Transitional Design: Chapter Conclusion

This chapter has described the formation and development of the Transitional Design Methodology, detailing the reflective methods, documentary process and the heuristic, multi-disciplinary and parallel approach to creative practice that contribute to the methodology. The practical element of the research, whilst being concerned with the technical development of the CPW system, is also a vehicle for implementing and testing the methodology, to determine the validity of the following hypothesis:

> The integration of hand and digital methods through simultaneous (rather than linear) experimentation, design and production, enhances innovation opportunities, stimulating and pushing the boundaries of both forms of production.

By employing, analysing and evaluating the Transitional Design Methodology, I have gained further insights into my own digital craft practice (i.e. ways of working, knowledge making and skills development) (Section 8.3.1) and have identified opportunities for future development, as well as establishing the methodological potential for wider application in craft and sustainable design contexts (Section 8.3.2).

3.9 References

ABBOTT, A. (2004). *Methods of Discovery: Heuristics for the Social Sciences*. London: W.W. Norton & Company Ltd.

ALBERS, A. (2000). *Anni Albers: Selected Writings on Design*. Hanover: University Press of New England.

BANG, A, L. (2010). 'Emotional Value of Applied Textiles: Dialogue-oriented and Participatory Approaches to Textile Design'. (PhD Thesis). Kolding: Design School Kolding.

CSIKSZENTMIHALYI, M. & CSIKSZENTMIHALYI, I, S. (1988). *Optimal Experience: Psychological Studies of Flow in Consciousness*. Cambridge: Cambridge University Press.

DICK, B. (2000) 'A Beginners Guide to Action Research'. *Resources Papers in Action Research*. Available at: http://www.uq.net.au/action_research/arp/guide.html. Accessed: 26 May 2018.

DIGITAL WEAVING NORWAY. (c.2018). 'TC2 Loom'. *Tronrud Engineering*. Available at: http://www.digitalweaving.no/tc2-loom/. Accessed: 25 June 2018.

DREYFUS, H, L. & DREYFUS, S, E. (1986). *Mind Over Machine: The Power of Human Intuition and Expertise in the Era of the Computer*. Oxford: Basil Blackwell.

GRAY, C. & MALINS, J. (2004). *Visualizing Research: A Guide to the Research Process in Art and Design*. Aldershot: Ashgate.

GWILT, A. (2011). 'Make - Producing Sustainable Fashion'. In: GWILT, A. & RISSANEN, T. (Eds.). (2011). S*haping Sustainable Textiles: Changing the Way we Make and Use Clothes*. London: Earthscan. pp.59-73.

HILES, D. (2001). 'Heuristic Inquiry and Transpersonal Research'. *The Virtual Office of Dave Hiles*. Available at: http://www.psy.dmu.ac.uk/drhiles/HIpaper.html. Accessed: 26 May 2018.

IRWIN, T. (2015). 'Transition Design: A Proposal for a New Area of Design Practice, Study, and Research'. Design and Culture. 7(2). pp. 229-246.

IRWIN, T. KOSSOFF, G. & TONKINWISE, C. (2015). Transition Design Provocation. Design Philosophy Papers. 13(1). pp. 3-11.

IRWIN, T. TONKINWISE, C. &. KOSSOFF, G. (2015). 'Transition Design: An Educational Framework for Advancing the Study and Design of Sustainable Transitions'. *6th International Sustainability Transitions (IST) Conference*. Brighton: University of Sussex. Available at: https://s3.amazonaws.com/academia.edu.documents/38615542/Irwin_Tonkinwise_Kossof_IP.pdf?response-content-disposition=inline%3B%20filename%3DTransition_Design_An_Educational_Framewo.pdf&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Credential=AKIAIWOWYYGZ2Y53UL3A%2F20190813%2Fus-east-1%2Fs3%2Faws4_request&X-Amz-Date=20190813T200138Z&X-Amz-Expires=3 600&X-Amz-SignedHeaders=host&X-AmzSignature=a736fed05fece3705883c61a165e58ffbe877737 b6019084605ce7bcbd24f1b8. Accessed: 13 August 2019.

JIANG, K. (2009). 'Time and Temperature'. in SANDU CULTURAL MEDIA CO LTD. (Ed.) (2009). *Fabric: Metallic Textile Design of Kinor Jiang*. Hong Kong: Sandu Publishing Co Ltd. pp. 25-47.

KLEINING, G. & WITT, H. (2000). 'The Qualitative Heuristic Approach: A Methodology for Discovery in Psychology and the Social Sciences. Rediscovering the Method of Introspection as an Example'. *Forum: Qualitative Social Research*. 1(1), Art. Available at: http://www.qualitative-research.net/index.php/fqs/article/view /1123/2495. Accessed: 26 May 2018.

LAWSON, B. (2005). *How Designers Think: The Design Process Demystified*. (4th Edition). Oxford: Elsevier Architectural Press.

LEHMANN, U. (2012). 'Making As Knowing: Epistemology and Technique in Craft'. *The Journal of Modern Craft*. 5(2). pp.149–164.

MALAFOURIS, L. (2013). *How Things Shape the Mind: A Theory of Material Engagement*. Cambridge: MIT Press.

MCCANN, J. & BRYSON, D (Eds.). 2009. *Smart Clothes and Wearable Technology.* Cambridge: Woodhead Publishing in Textiles.

MCNIFF, J. LOMAX, P. & WHITEHEAD, J. (2003). *You and Your Action Research Project* (2nd Edition). London: Routledge Falmer.

MCNIFF, J. (2013). *Action Research: Principles & Practice* (3rd Edition). London: Routledge.

MCNIFF, J. (2002). 'Action Research for Professional Development: Concise Advice for New Action Researchers (3rd Edition)'. *Jean McNiff*. Available at:
http://www.jeanmcniff.com/ar-booklet.asp. Accessed: 12 April 2014.

MCQUILLAN, H. (2011). 'Make – Zero-waste Design Practice: Strategies and Risk Taking for Garment Design'. In: GWILT, A. & RISSANEN, T. (Eds.). (2011). S*Shaping Sustainable Textiles: Changing the Way we Make and Use Clothes*. London: Earthscan. pp.83-97.

MCQUILLAN, H. (2010). 'Holly McQuillan: Projects'. Holly McQuillan Available at: http://hollymcquillan.com/. Accessed: 04 December 2013.

NIKE. (2016). 'Top Things to Know About Sustainable Innovation at Nike'. *Nike Inc*. Available at: https://news.nike.com/news/sustainable-innovation. Accessed: 27 May 2018.

NIMKULRAT, N. KANE, F. & WALTON, K. (Eds.) (2016). *Crafting Textile in the Digital Age*. London: Bloomsbury.

O'CONNOR, E. (2007). 'Embodied Knowledge in Glassblowing: The Experience of Meaning and the Struggle Towards Proficiency'. *The Sociological Review*. 55(S1). pp.126–141.

PEDGLEY, O. (2007). 'Capturing and Analysing Own Design Activity'. *Design Studies*. 28(5). pp.463–483.

PHILPOTT, R. (2012). 'Crafting Innovation: The Intersection of Craft and Technology in the Production of Contemporary Textiles'. *Craft Research*. 3(1). pp. 53–74.

PHILPOTT, R. (2011). 'Structural Textiles: Adaptable Form and Surface in Three Dimensions'. (PhD Thesis). London: Royal College of Art.

PIPER, A. & TOWNSEND, K. (2015). 'Crafting the Composite Garment: The Role of Hand Weaving in Digital Creation'. *Journal of Textile Design Research and Practice*. 3(1-2). pp.3-26. Available at: https://www.tandfonline.com/doi/abs/10.1080/20511787.2015.1127037. Accessed: 10 November 2018.

PIPER, A. (2014). 'Crafting the Composite Garment: The Role of Hand Weaving in Digital Production/Creation'. T*ransitions: Rethinking Textiles and Surfaces*. Huddersfield: University of Huddersfield. 26-27 November 2014.

REASON, P. & BRADBURY, H. (Eds.). (2001). *Handbook of Action Research (Concise Paperback Edition)*. London: SAGE.

RISSANEN, T. & MCQUILLAN, H. (2016). *Zero Waste Fashion Design*. London: Bloomsbury.

RISSANEN, T. (2013). 'Zero-Waste Fashion Design: A Study at the Intersection of Cloth, Fashion Design and Pattern Cutting'. (PhD Thesis). Sydney: University of Technology.

ROBERTS, J. (2014). 'Zero Waste Questionnaire'. *Subtraction Cutting by Julian Roberts*. Available at: https://subtractioncutting.tumblr.com/post/86887883276/zero-waste-questionnaire. Accessed: 26 May 2018.

ROSSO, B, D. (2014). 'Creativity and Constraints: Exploring the Role of Constraints in the Creative Processes of Research and Development Teams'. *Organization Studies*. 35(4). pp. 551-585.

SCHÖN, D, A. (1991). *The Reflective Practitioner: How Professionals Think in Action*. London: Ashgate.

SWANN, C. (2002). 'Action Research and the Practice of Design'. *Design Issues*. 18(2). pp. 49-61.

TAYLOR, J. (2015). "The Technical Designer: A New Craft Approach for Creating Seamless Knitwear'. (PhD Thesis). Nottingham: Nottingham Trent University.

TAYLOR, J. & TOWNSEND, K. (2014). 'Reprogramming the Hand: Bridging the Craft Skills Gap in 3D/digital Fashion Knitwear Design'. *Craft Research.* 5(2). pp.155–174.

THOMAS, L. (2009). 'Woven Structures and Their Impact in the Function and Performance of Smart Clothing'. In: MCCANN, J. & BRYSON, D. (Eds.). (2009) S*mart Clothes and Wearable Technology*. Cambridge: Woodhead Publishing in Textiles. pp.131–155.

TOWNSEND, K. & MILLS, F. (2013). 'Mastering Zero: How the Pursuit of Less Waste Leads to More Creative Pattern Cutting'. *International Journal of Fashion Design, Technology and Education*. 6(2). pp. 104–111.

TOWNSEND, K. (2004a). 'Transforming Shape: A Simultaneous Approach to the Body, Cloth and Print for Textile and Garment Design (synthesising CAD with Manual Methods)'. (PhD Thesis). Nottingham: Nottingham Trent University.

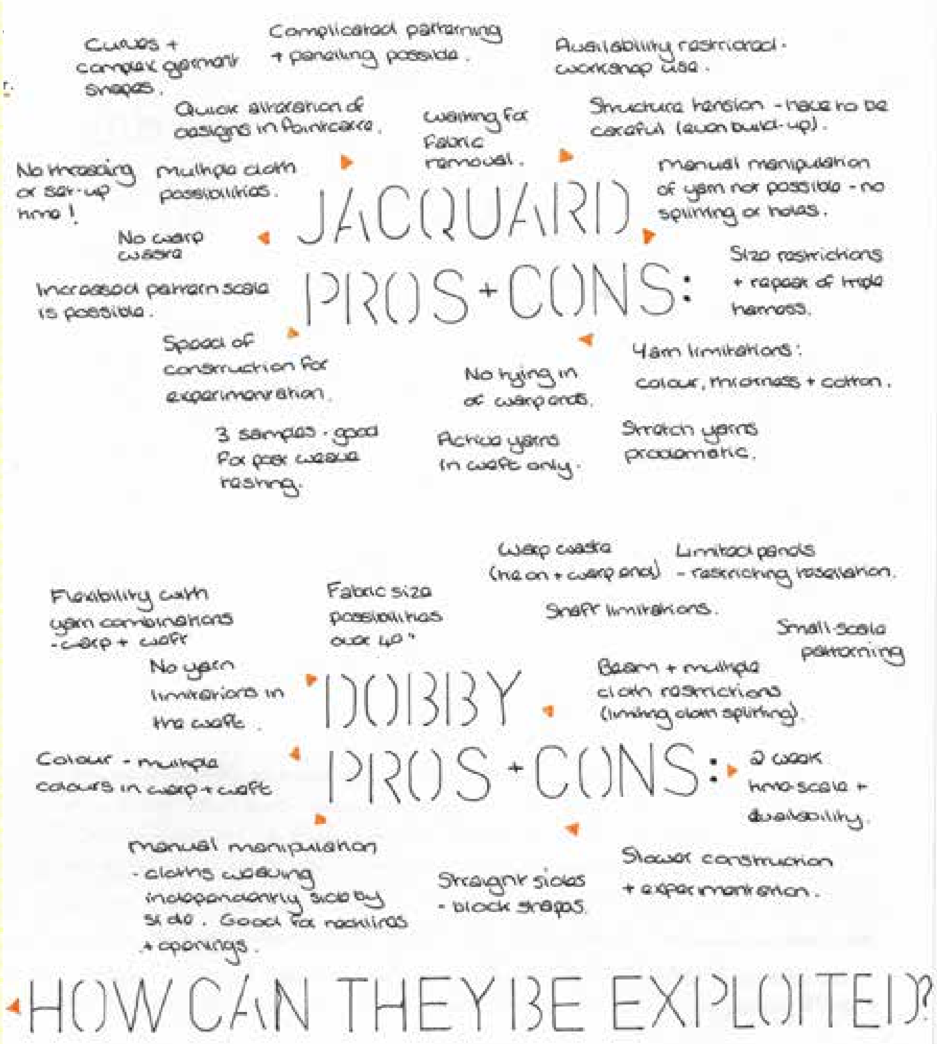
TOWNSEND, K. (2004b). 'Transforming Shape: Hybrid Practice as Group Activity'. *The Design Journal*. 7(2). pp. 18-31.

TRULLEN, J. & TORBERT, B. (2013). 'First-, Second-, and Third-Person Research in Practice'. *The Systems Thinker*. Available at: https://thesystemsthinker.com/first-second-and-third-person-research-in-practice/. Accessed: 26 May 2018.

WOOD, N. (2006). 'Transmitting Craft Knowledge: Designing Interactive Media to Support Tacit Skills Learning'. (PhD Thesis) Sheffield: Sheffield Hallam University.

3 Journal Excerpts

Selected MA Journal Entries (Excerpt 3.1)



Week 28: Garment Development and Recording

I've decided that I want to make major inroads into the development of garment shapes. I have had lots of ideas that I really need to try out. I would like to ensure that all the technical developments/processes are utilised across the hand and Jacquard woven garments [...] Once the garments are designed, the fabrics and patterns can be developed to work both technically and aesthetically with the shapes.

Starting to work on this dress has brought a few issues to the surface. Firstly, my initial designs may not be possible on the Jacquard e.g. the size restrictions mean that there is not enough space for the pockets. The first pleat dress *design I worked on a few weeks ago is also problematic – it needs to be woven across the width of the dress (due to the shrink yarns) but the loom set-up is not wide enough to accommodate the pleats. Now that I have seen the half scale Jacquard top being woven I don't think that tessellating garments on the Jacquard (with this set-up is possible – again there is not enough space). However, multiple different garment variations could be produced in a single length on the hand loom.*

I am working on multiple garments at the same time:

- *The first bodice toile was developed and designed, and is now in the Pointcarre/weaving stage*
- *The dart-top skirt has been started (in toile form) but is on hold until the woven dart is tried and tested*
- *The first dress is in development on the stand with the design idea sparked by the development of the top.*

Recording the development of the garments chronologically would be a better record of the process, as the things learned from the development of one toile, for example, could impact on the development of the next, and so on – with the design process between garments becoming interconnected rather than independent.

Week 35: Toiles

Having done work with paper and yarn on the mannequin, these initial toiles seem too basic – particularly the dress, but these are not in any way final designs. The jacket could be developed further on the hand loom in conjunction with thicker fabrics and pockets. I think using the toiles to develop and test out basic designs and then selecting more successful one for development is a good way forward, and in doing so I can use the toile designs to refine the Jacquard process.

Week 41: Jacquard Testing: Design, Design, Design

One of the things that is really concerning me about the Jacquard part of the project is highlighted by these samples. Structures/lifting plans taken from hand weaving can appear totally different when woven on the Jacquard. So, I am not confident about the way my Jacquards will look when woven. There are a number of patterns I want to take through into Jacquard – the stripe, grid and diamond, as well as the triangle and circle in the style of a weave structure. The weave structures for me visually connect the process.

Week 44: Jacquard Weaving

I have now produced a design that incorporates randomly placed coloured spots. This has been achieved using extra weft – a technique I have used extensively on the hand loom but never before on the Jacquard […] The positive outcomes in the last Jacquard session have spurred me on to work more on designs that combine colour and multiple geometric patterns to reflect the panel effects in my sketchbook and in the recent hand woven designs.

Jacquard Design Options

- *Using/maintaining grids and stripes to tie in with hand-woven designs.*
- *Combination of scales within samples and across the collection.*
- *Use of light and dark as dominant.*
- *Spots softening and bringing in the non-angular whilst still being graphic*

Re-establishing the Boundaries of Practice (Excerpt 3.2)

Posted: 9th January 2017

During the process of threading the TC2 I was struck by the lack of boundaries the loom provides for directing design. Until this point my process and methodology has been based on the different constraints each mode of production provides which has resulted in a transitional process of moving between hand and digital production. This lack of boundaries is a frightening prospect as it destabilises my process and throws into question my methodology – is it still valid?

So, I have started to think about the constraints/parameters still present in the process when using the TC2:

- *The width of the cloth and its rectangular nature*
- *The biaxial construction – horizontal insertion and intersection of yarns*
- *The type and colour of the warp yarns*
- *Minimisation of waste impacting on the silhouette*
- *Functionality of the fabric and the garment (in terms of wear and aesthetic)*
- *Active yarns (when used in the warp) being continuous in the cloth even when shaping and movement is not required*
- *Jacquard and hybrid – the warp is not design for specific pieces/garments*

These parameters can be categorised into those that are imposed by the loom and the weaving process, and those that are imposed by me (sustainability, aesthetic, garment functionality) – Self-Imposed Parameters and Process Parameters. The primary constraint is that of the production of the rectangular fabrics with the dimensions of the cloth width being imposed by the loom itself. As such, this rectangular block can be the initial starting point for any design. By extension, this then links to the production of and minimisation of waste that will inform the silhouette and components of each garment. Furthermore, on the hybrid loom, the warp is not specifically designed with each garment or technique in mind – the warp yarn and density will remain the same in all garments. This will influence both the structure and aesthetics of designs. As a result, the hand loom retains an advantage over the hybrid loom – the warp can be designed specifically for a garment (colour, yarn type, density etc.), so whilst the hand loom does not have the flexibility of the TC2 when it comes to silhouette shaping, it provides greater opportunity for the exploration of fibres (characteristics and colour).

Tagged: Design, Methods, Opportunities, Questions, Uncertainty

Technical Testing: Emerging Patterns (Excerpt 3.3)

Posted: 23rd July 2014

As I begin to weave I try to establish if the pattern is weaving correctly – it is hard to see with only a few picks completed, so I stop and pick at the threads to locate the position of the floats. Slowly a shadowy subtle pattern begins to emerge, during a very stop-start period of weaving. There is no flow, the process is messy, the shuttle is tentatively placed and pushed through the shed – the focus is on checking the construction rather on a smooth succession of actions (press the treadle, push the reed, insert the shuttle, collect the shuttle, lower the treadle and pull the reed to beat the weft).

Having checked the pattern is correct, floats in unexpected places throw me. It is too soon to know if this is a mistake in the lifting plan or an error in the weaving itself. When I am happy with the pattern, the weaving becomes smoother and the focus moves from the basic construction to the quality of the weaving e.g. 'Are the edges straight and even?'. I focus on this aspect of weaving for a while, making slight adjustments (trying and failing to place the shuttles in the correct order as I swap them over) to my actions until I am happy that any issues are resolved. The focus then shifts again, back to the pattern itself, a few repeats have been completed, making the full scale of the pattern evident = the position of the floats and the outline shape is elongated. I am concerned – will this impact on the ability of the fabric to fold into the intended structure? There is no way of knowing until the fabric is finished, and so I continue, making a mental note that ways of addressing this will need to be considered.

As weaving progresses, my mind wanders, and my focus is not lost but I am not actively aware of individual actions and elements of the process unless something unexpected occurs – a snagging thread, an overly heavy or overly light lift, odd looking thread patterns as the warp is lifted. Issues are resolved, and I return to the rhythmic building of the cloth.

Tagged: *Awareness, Expectation, Challenge, Problem-solving, Mistakes, Repetition, Uncertainty*

Weaving Cycle #1: Warping with Extras (Over, Under, Under, Over, Round) (Excerpt 3.4)

Posted: 23rd June 2014

This is the first warp I have made for almost a year and so I expected to be a little rusty, for it to take a bit of time to get into the flow. But it was actually as though I had never been away. I automatically, and without thinking, wrap the warp in the 'correct' direction around the pegs (the direction that feels natural and comfortable), and am instantly aware that if, for some reason, I alter the direction it feels wrong, then it subsequently slows me down. This change of direction generally follows a distraction.

As always, the target is the perfect warp in the minimum amount of time. Tidying up the warp as I go along – running my hand along the yarns as I wrap to push them together – neatening and then checking for miss-wraps around the pegs (where the peg has been missed out in error) – being disappointed to find one. But I know, in reality, this is not a problem, they can be threaded back through the sticks in threading if required.

I choose to come to the weave room first thing, when no one is around, to minimise distractions – I know from experience that I am easily distracted, but even without the distraction of others, I am distracted by my own thoughts – finishing, an itch on my neck, filming, the process of reflection (e.g. I have said I am going to do x, y, z – I need to make sure I am doing this), being overly conscious of and trying to remember my actions, and then thinking 'should I be doing this or not?'.

Consciously counting throughout. Distracted by thoughts and by others coming in and out of the room. Forgetting what number I am on, mis-counting, realizing and then consciously thinking "focus on counting". People speak to me – in some cases I carry on and in others I stop; aware that when carrying on I lose count or make a mistake. Thinking about if I need to tell them that I am filming.

Weaving Cycle #1: Warping with Extras (Over, Under, Under, Over, Round) (Excerpt 3.4 - Continued)

I am not really aware of how long the warping is taking. Then I look at my watch and set a target for completions – 10:00am. In no real rush today and so this is just an ideal time rather than a deadline. The number of bundles completed act as milestones – ¼ of the way through, ½ way through, ¾ of the way through – checking the bundles when I think I have met the milestone. Counting – if on the first count it matches what I am thinking, I count only once, if it doesn't match I repeat the count to be sure [...]

Tagged: Intuition, Knowledge Application, Material Engagement, Targets/Goals

Reflective Practice: Design Reviews (Excerpt 3.5)

Posted: 22nd February 2017

In the textile sampling phase of the project I had completed design review sheets to capture the development of the processes, and to allow me to systematically reflect on the stages of development - considering the moves, consequences, implications, appreciations and further moves. This seemed logical and useful when developing multiple textiles alongside each other in a more technical context.

Last week I realised that I had not been using the review sheets when developing the garments, so started one for the cape design. My intention this morning was to begin one for the top. But before I started I thought to myself that back dating this would be pointless, and I would need to refer back to my journal and sketchbook notes to do it. Looking back at the blog and my sketchbook it is clear that I already capture this information in my annotations and reflections. Designing is a different process to technical sampling - rather than constructing the samples and analysing them (formally), I note down ideas, problems, decisions and questions as I go. I am analysing and reflecting during the activity (In Action) and post activity (On Action). As such the design review sheet seems unnecessary. A duplication. A waste of time. So, I am not going to do it! I just need to ensure that I am actively considering the following in my reflection:

- *Moves: action taken and the problems*
- *Consequences: establishing solutions and the consequences of those solutions*
- *Implications: for the current design, the process etc.*
- *Appreciations: for the wider concept, sustainability, functionality etc.*
- *Further Moves: keeping track of the next steps and the impacts*

Tagged: *Reflection, Methods*

4 Composite Pattern Weaving:

Technical Context

4 Composite Pattern Weaving:

Technical Context

4.1 Technical Aim

To explore the design potential of composite pattern weaving and single-piece garment weaving as an alternative to conventional cut-and-sew construction, by developing 3D prototypes that test and demonstrate the flexibility of the Composite Pattern Weaving system.

4.2 Technical Context: Chapter Overview

Composite Pattern Weaving (CPW) is the production of engineered zero waste patterns (or lay-plans), incorporating seamless integral textile shaping and functional panelling, constructed as a single piece on the loom. This chapter outlines the technical context which gave rise to the CPW system.

By considering the existing examples of single-piece, fully-fashioned and composite garment weaving found in craft, performance and commercial woven production, the chapter exposes a dearth of woven garments, particularly in commercial fashion (Section 4.5) and highlights the absence of significant advancements in seamless weaving technologies relative to fully-fashioned and seamless knitted garment construction (Section 4.3). The CPW system builds upon the findings of existing studies into fully-fashioned and composite garment weaving; responding to their limitations (i.e. material use, styling and garment types) and recognising the sustainable potential of these forms of garment production to reduce material consumption, by minimising cutting waste, seam allowances and post-weaving garment construction (Section 5.6).

By reflecting upon the properties and characteristics of woven textiles (in comparison to knitted construction), and their means of production/construction, Section 4.6 outlines the complexities of integrally shaping woven textiles and garments, as well as identifying yarn and weave structure manipulation techniques and principles (observed in craft weaving and applied in industrial weaving to generate textural effects (Section 4.4)). These principles and techniques provided the starting point for technical exploration during the Component Construction phase of the research (Section 7.3) and were adapted and applied in this study to the integral shaping of garments (Section 7.5-7.10).

4.3 Single-piece, Fully-fashioned and Composite Garment Weaving

There has been limited research undertaken into single-piece garment weaving in comparison with the growth in research into integrally shaped seamless fashion knitwear (Ng et al. 2010; Wang et al. 2009). To date, research into three-dimensional weaving has generally concentrated on industrial and medical applications rather than for fashion apparel (Wang 2011; Ng 1999).

Weaving presents significant challenges for fashioning and shaping textiles due to the predetermined unchanging width of the warp, and the use of two yarn sets (warp and weft) (Jayaraman & Park 2001). These constraints, along with the absence of significant advancements in seamless weaving technologies capable of producing garments, have restricted design-led research into fully-fashioned and composite garment weaving (Wang 2011; Jayaraman & Park 2001).

This section describes the current context of fully-fashioned, single-piece and composite garment weaving. It identifies the developments that have taken place in functional clothing and commercial fashion, as well as considering the small-scale production of hand crafted and bespoke woven garments.

4.3.1 Contemporary Craft Context

Fully-fashioned, single-piece and seamless garment knitting have flourished due to advances in knitting machines and associated software (such as Shima Seiki's WHOLEGARMENT ® (2015) and Santoni's (c.2014) seamless knit technologies), and

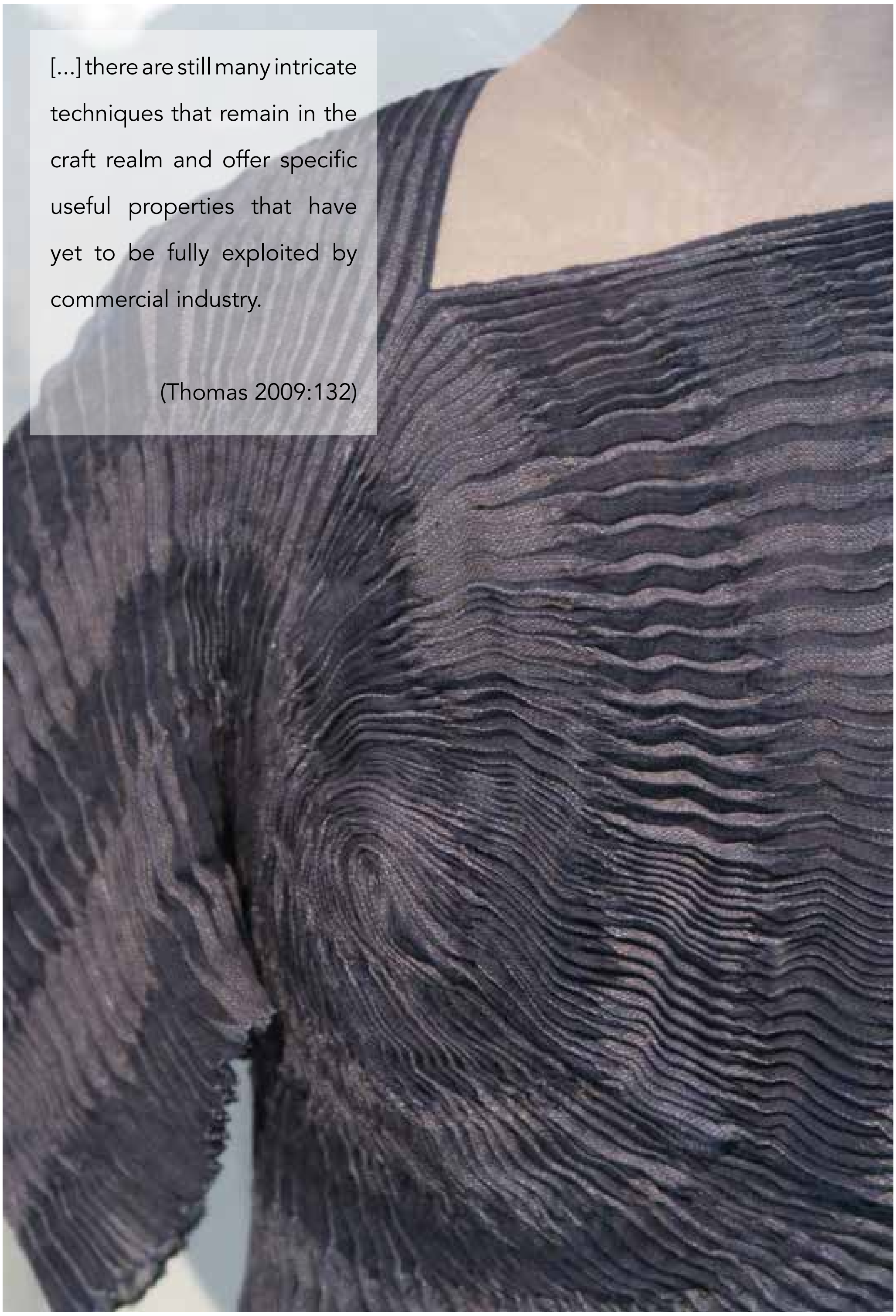


Figure 4.1: Audrey Dress (2009) by Lotte Dalgaard and Ann Schmidt-Christensen
Photograph by Anna Piper

the demand for seamless construction in fashion, functional and performance garments (specifically sportswear). Conversely, loom-shaped woven garment construction has diminished and is largely consigned to hand weaving in the craft realm (with a few notable exceptions – see Sections 4.3.2 and 4.3.3).

> […] making seamless woven garments via peculiar hand-weaving methods.
>
> (Lee 2016: 6)

Figure 4.2: Seamless Woven Jacket (2013) by Yeseung Lee
Photograph by Anna Piper

Lotte Dalgaard is perhaps one of the most well-known and respected exponents of contemporary loom-shaped weaving, producing textural and pleated textile blocks (or components). Working in collaboration with fashion designer Ann Schmidt-Christensen, garments are designed and constructed in response to the qualities of the woven cloth (Figure 4.1) – stitched together but not cut. The garments have a hand crafted aesthetic with textures and loose draping silhouettes, using muted and neutral colour combinations that echo and emphasise the organic characteristics of the fabric construction (see Dalgaard 2012 for a detailed overview of her processes, textiles and garments).

Loom-shaped woven garments are constructed from multiple (usually rectangular) blocks woven to the required dimensions and stitched together. The simplicity of the design often results in loose unstructured pieces. The loom-shaped weaving technique is often used in conjunction with the 3D and shaped weaving techniques outlined in Section 4.4, to introduce textural and structural decorative effects.

Yeseung Lee's garments are a variation on traditional fully-fashioned garment weaving (see Lee 2016). Using industrially woven fabrics, rather than weaving the fabrics herself, Lee constructs seamless woven garments by deconstructing the edges of the fabric and reconstructing the cloth – 'weaving' pieces together with a sewing needle to connect the cloth without a conventional seam (Figure 4.2). The woven structure of the fabric is a prominent feature of the garments that drape around the body. When pieces of the same fabric are connected, the join is rendered invisible, creating the illusion of a garment constructed in a single piece. But when combining contrasting colours, the integration of threads results in a contemporary graphic patterning where the seam is removed but the assimilation remains visible.

Founded by fashion designers Pascale Gatzen, Mae Colburn, Nadia Yaron and Jessi Highet, the New York-based weaving co-operative friends of light create bespoke hand woven jackets, using natural fibres sourced from local producers (de Klee 2016). Shaped pattern pieces are individually woven using their own hand-made looms. The looms are constructed on a wooden board with a series of pins positioned to form the outline of the pattern piece. Vertical threads are attached to the pins to create the shaped warp (Figure 4.3). The weft yarns are manually and intricately passed over and under the warp threads, in a process akin to tapestry weaving. Working in this way, friends of light are able to produce curved and tapered pattern pieces that require no cutting before being stitched together.

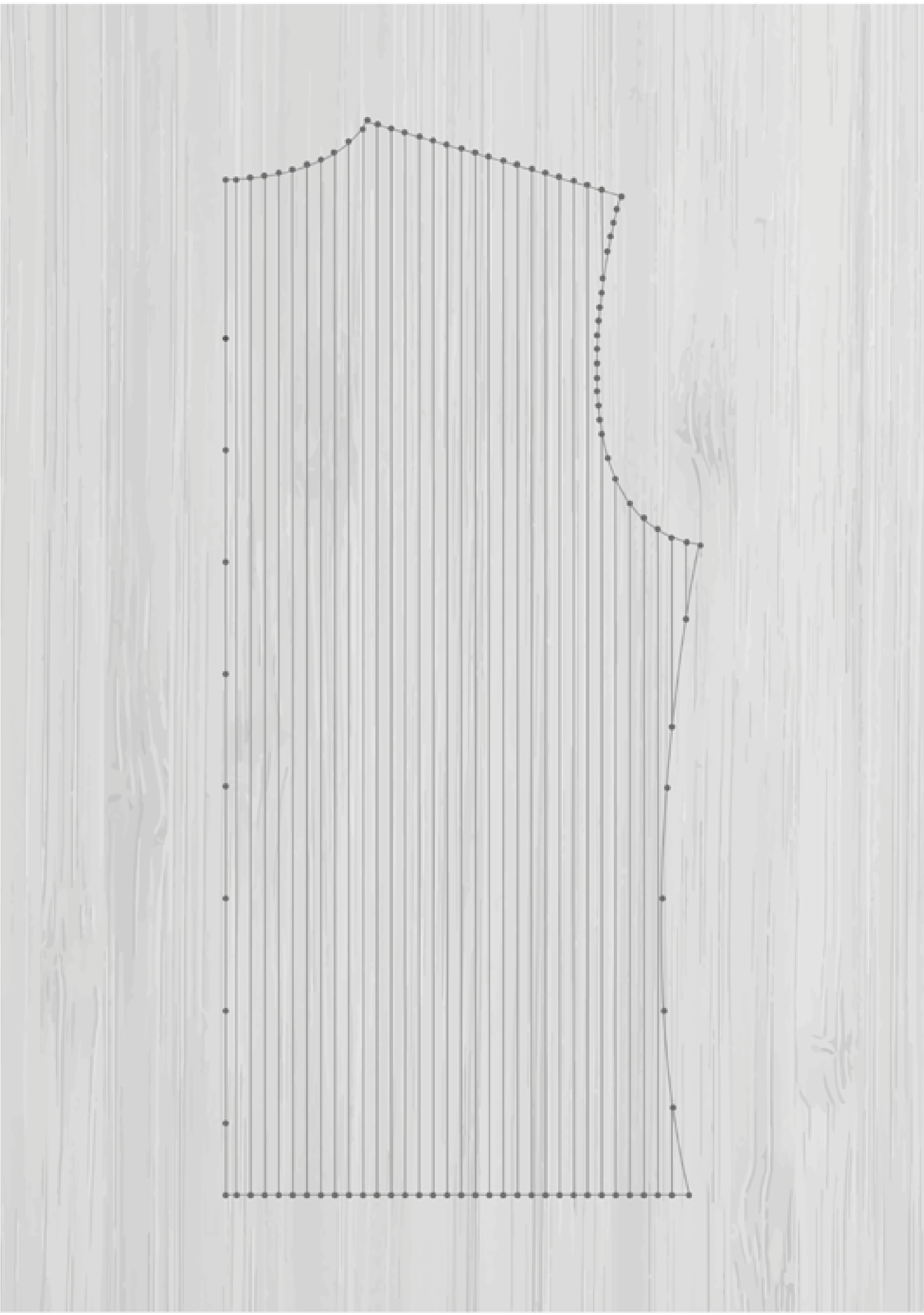


Figure 4.3: Friends of Light Loom for Pattern Piece Construction (2018)
Illustration by Anna Piper

Brooklyn-based design studio Manonik, founded by Yoshiyuki Minami, has developed a weaving technique referred to as "Three Dimensional Pattern Weaving" (2017), whereby garment components, such as sleeves, buttonholes and necklines are constructed on a hand loom using a combination of double cloth weaving and hand manipulation techniques. Pattern pieces and components are shaped on the loom by selectively weaving sections of the warp, (leaving some sections unwoven) and by using a needle and thread to mark and seal the edges. Once removed from the loom the pieces are seamed and stitched together to produce beautifully crafted, deceptively simple (unstructured and oversized), one-off garments.

These examples represent complex craft-based variations on the tradition of loom-shaped weaving; all of which are generated by and evidence a hand-crafted aesthetic, attributable not only to their draping and unstructured silhouette but also the use of predominantly natural fibres and neutral colour palettes. They demonstrate an advanced application of skills and knowledge of textile construction, but are limited in their fibre usage, integration of structural/3D shaping and contemporary fashion aesthetic (including colour, pattern and fabric quality).

4.3.2 Functional Composite and Single-piece Garment Weaving

The 'Wearable Motherboard' (Jayaraman 1996-98 in Colchester 2007) was the first seamlessly woven garment integrating intelligent technology to monitor the wearer's vital signs. This was followed by a number of construction process patents by Jayaraman and Park (2001), Jayaraman et al. (2000) and Osborne (2010) for functional and utility garments. Jayaraman's patents outline fully-fashioned weaving processes, using "Tubular Weaving", for the production of single-piece seamless garments incorporating armholes and sleeves for the purpose of integrating wearable technologies for data collection. Osborne's patent features a complex Jacquard woven compression vest, using single and double cloth weaving and stretch fibres. Incorporating multiple pouches and layers, the garment is woven in a single piece and requires sewn seams and additional fastenings.

The integration of smart technologies in seamless textiles and garments is most prevalent in knitwear, where the single yarn looped construction has been developed to form conductive circuits and sensors for medical applications. Examples include Nottingham Trent University's heated textile gloves (2015), which uses conductive yarns and knitted structures to produce knitted heated elements for use in the treatment of Raynauld's Disease. Similarly, the Vigour project, developed at Eindhoven University of Technology in collaboration with researcher Martijn ten Bhömer and fashion designer Pauline van Dongen, uses stretch sensors made from "wool-like conductive yarns" (Kuusk 2016),

> [...] serveral functions in a single smooth layer to respond to the specific needs of each body part.
>
> (Bramell 2005: 26)

Figure 4.4: Aeolia Project: Garments Incorporating Stretch Sensors (2010)
By Marshall, Glazzard, Downes and Harrigan

to monitor physical movement of geriatric patients undertaking physical rehabilitation. The sensors, integrated into a knitted cardigan, gather and transmit movement data to an iPad to allow the wearer, medical professionals and family members to monitor their progress (ten Bhömer 2016; van Dongen 2016).

Additionally, the integration of devices and sensors to monitor sports performance is becoming more common in sportswear (see for example Textronics (2016)). The seamless construction of composite and single-piece garment weaving and seamless knitting enables the embedding of a continuous electronic circuit into a garment during construction, to aid effective distribution of sensors on and around the body to detect signals (Watkins & Dunne 2015) (Figure 4.4).

> Seamless garments have gained huge popularity because of the speed at which such garments can be produced and the unique combination of properties they provide - including comfort, a smooth fit, light weight, an aesthetically pleasing appearance and ease of care.
>
> (Textiles Intelligence 2018)

Furthermore, seamless woven and knitted construction also facilitates the assimilation of multiple structures "to combine several functions in a single smooth layer to respond to the specific needs of each body part." (Bramell 2005: 26). This approach has been used widely in knitted sports and active-wear (see Nike's Hyperwarm Flex performance wear (Nike 2014)). With the growing popularity and ongoing trend for sports and functional fashion, seamless garment construction is becoming a feature of everyday wear and high fashion. Despite the increasing interest, and functional and stylistic potential of such products, research into fully-fashioned and single-piece garment weaving remains limited.

4.3.3 Fully-fashioned and Composite Garment Weaving in Fashion

In the small number of studies where fashion applications have been considered they have generally concentrated on "shapeable stretch textiles" (Ng et al. 2010; Wang et al. 2009) using digital Jacquard looms, with techniques applied to a limited garment range. Employing tubular garment construction, shaping has been confined to a single 'active' yarn type (such as elastane) used in the weft, with limited emphasis being placed on the design aesthetic (styling, pattern and colour). In focussing on the use of stretch fibres, these woven garments mimic the close fitting styles better suited to the properties and characteristics of knitting (Sections 4.6.2).

Hellen van Rees is one of the few contemporary fashion and textile designers to work with fully-fashioned garment weaving in a commercial context. Her garments combine woven textiles with heat fusing processes to produce seamless garments created entirely by hand. Her unconventional approach uses an 'off-loom' method of construction whereby recycled yarns (pre-consumer factory waste) are loosely inter-woven through layering on a flat surface. The textile is constructed in the shape of the garment component/pattern piece and is heat fused to give the fabric stability, durability and wearability (van Rees 2014).

To date, Issey Miyake's A-POC, developed with Dai Fujiwara is the most high profile single-piece woven garment, incorporating the strongest emphasis on design aesthetics. Discussing A-POC in 2001, Miyake said:

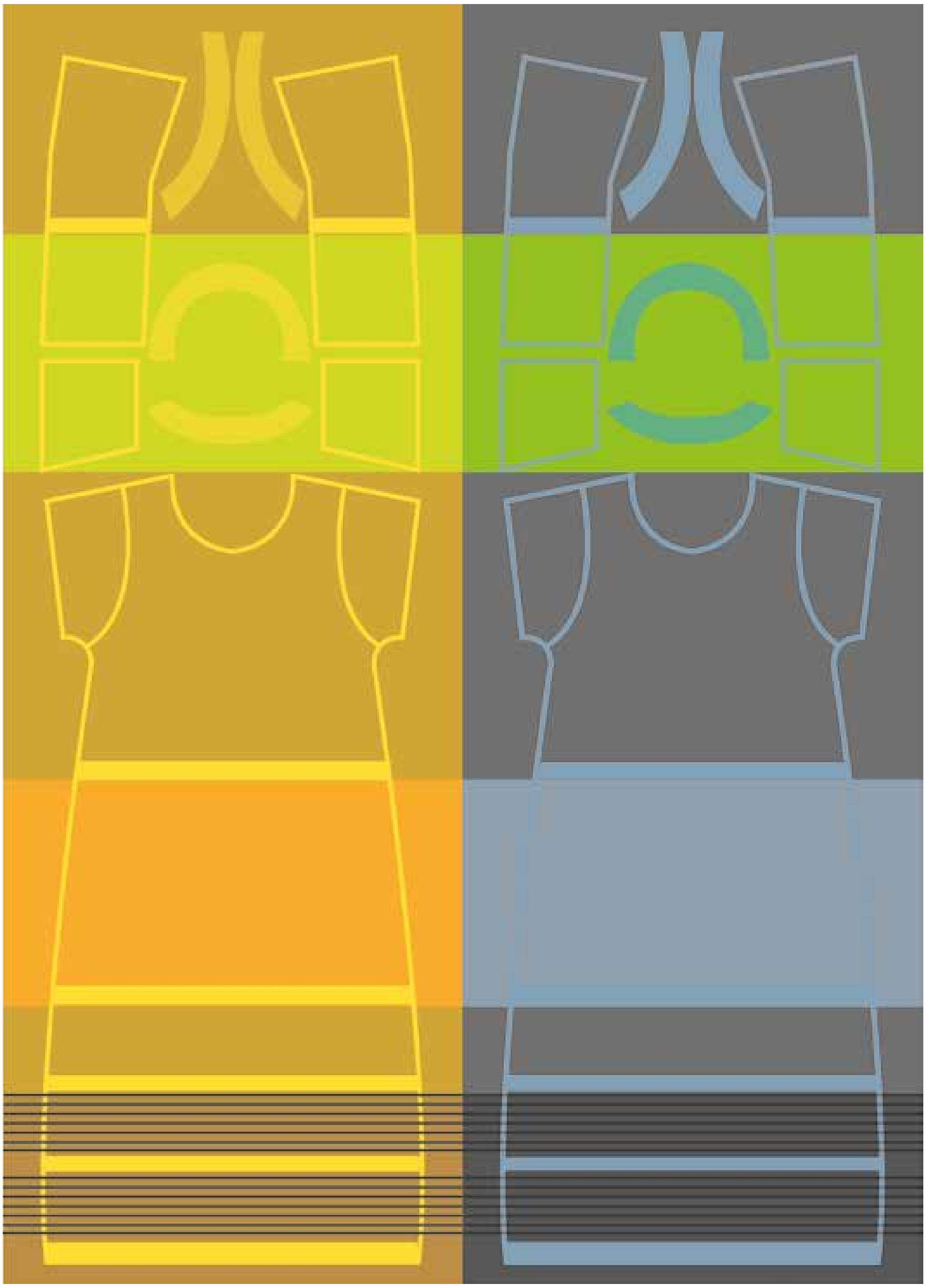


Figure 4.5: A-POC Framework (2001) by Issey Miyake
Illustration by Anna Piper Based on Illustration in Vitra Design Museum (2001)

> A-POC has transported craft into the 21st Century [...] we have discovered skilled means of programming a futuristic weaving machine capable of producing complete ready-to-wear garments from a single thread.
>
> (Rudge 2001: 24)

Miyake's A-POC concept was primarily applied to knitted garment construction, however a number of woven pieces were produced, including Frame Work (2001), Pain de Mie (2000) and Caravan (2000) (see Vitra Design Museum 2001). The pieces promoted the idea of minimum waste and personal customisation by enabling customers to cut a variety of simple garment shapes and accessories from a length woven from single and double cloth structures (Figure 4.5).

Although produced for the commercial fashion market, both Miyake and van Rees' woven concepts remain specialist and small-scale. Miyake's A-POC in woven form is not available in-store, whilst the knitted form continues to be developed and features in seasonal collections. Both approaches are unconventional in their application of woven construction, not only because they apply fully-fashioned and composite woven construction techniques (unlike Miyake's later works such as his Steam Stretch and Baked Stretch concepts/collections (Section 4.5)), but also because van Rees' method is entirely 'off-loom' and Miyake's requires specially adapted "weaving machines" (Miyake in Rudge 2001: 24).

During the course of this research (2013-2018), weaver Jacqueline Lefferts (2015) has recognised the sustainable potential of fully-fashioned and composite garment weaving. Lefferts, through the development of integrally shaped composite woven garments (achieved through "weave structure and material choice" (2015))[1], explores the ability of this form of garment construction to reduce material waste and the "carbon footprint of a product" (Ibid) by eliminating sewing and off-loom construction. Constructed using synthetic fibres and a single repeat Jacquard loom, Lefferts' integrally shaped garments are akin to Miyake's A-POC concept, in that garments are cut out of the length of cloth resulting in the production of cutting waste (Figure 4.5).

In this research (and that of Lefferts), processes and construction techniques are being developed using un-adapted widely available weaving looms (Section 7.2) and digital software (Pointcarre and Adobe Illustrator). As such, there is scope for construction processes to be more widely adopted in the fashion and textile industry.

[1] Sources relating to Leffert's work provide no further information about the weave structure and yarn combinations employed in the integral shaping of garments.

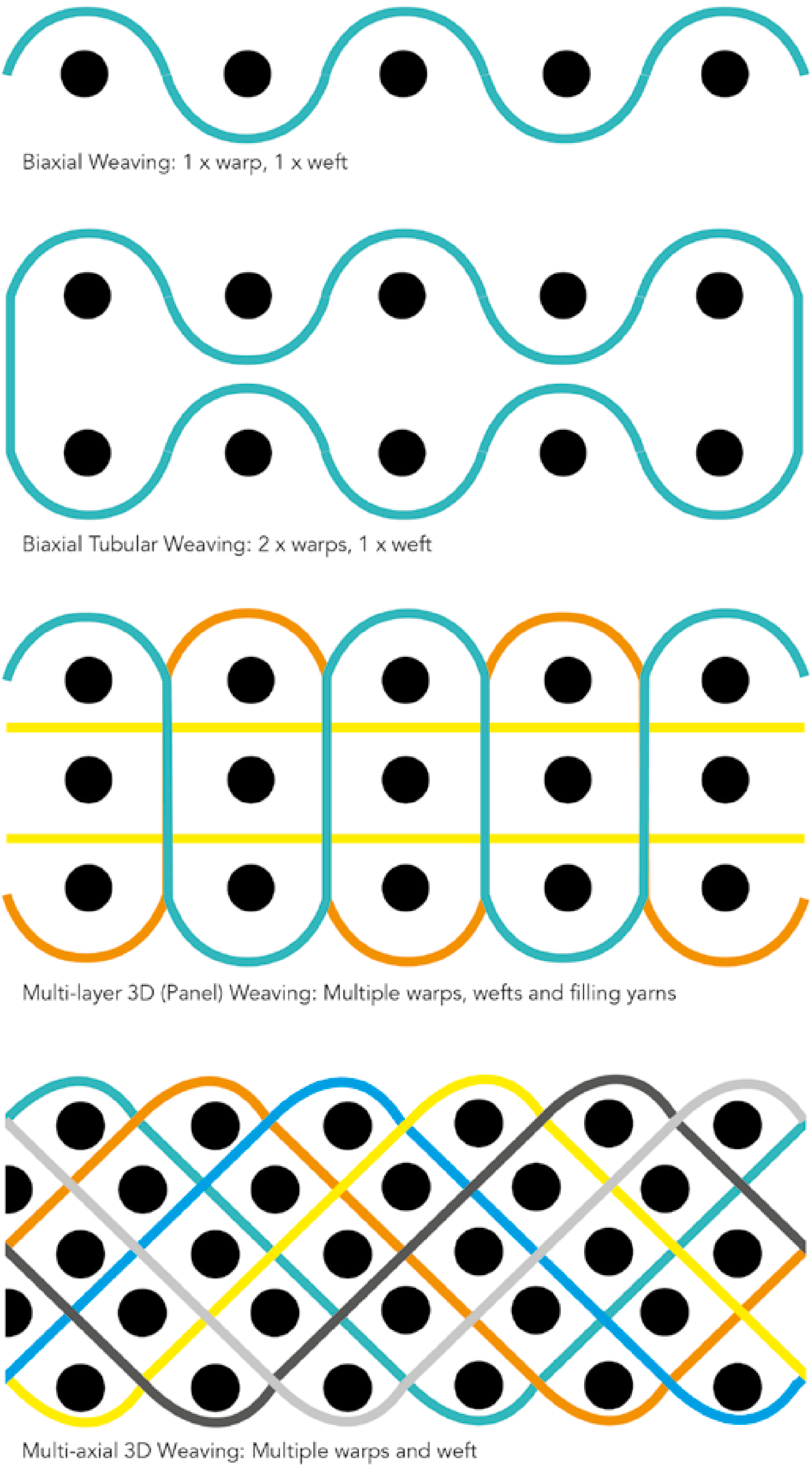


Figure 4.6: 3D Woven Fabric Categories: Biaxial and Multi-layer Weaving (2016)
Illustration by Anna Piper

4.4 3D and Shaped Woven Textiles

The term 3D weaving is applied to a range of different types of woven construction. The term has caused significant debate particularly in the field of technical textiles, where researchers seek to establish what 'true' 3D weaving is (Behere & Mishra 2008). In craft-based textile disciplines woven textiles are often referred to as 3D when form is actually generated, by manipulating yarn properties and weave structures, in single or multi-layered fabrics. These attempts to categorise and define 3D woven fabrics are based on the number of warps and wefts used in construction, and the angle at which they intersect (Figure. 4.6).

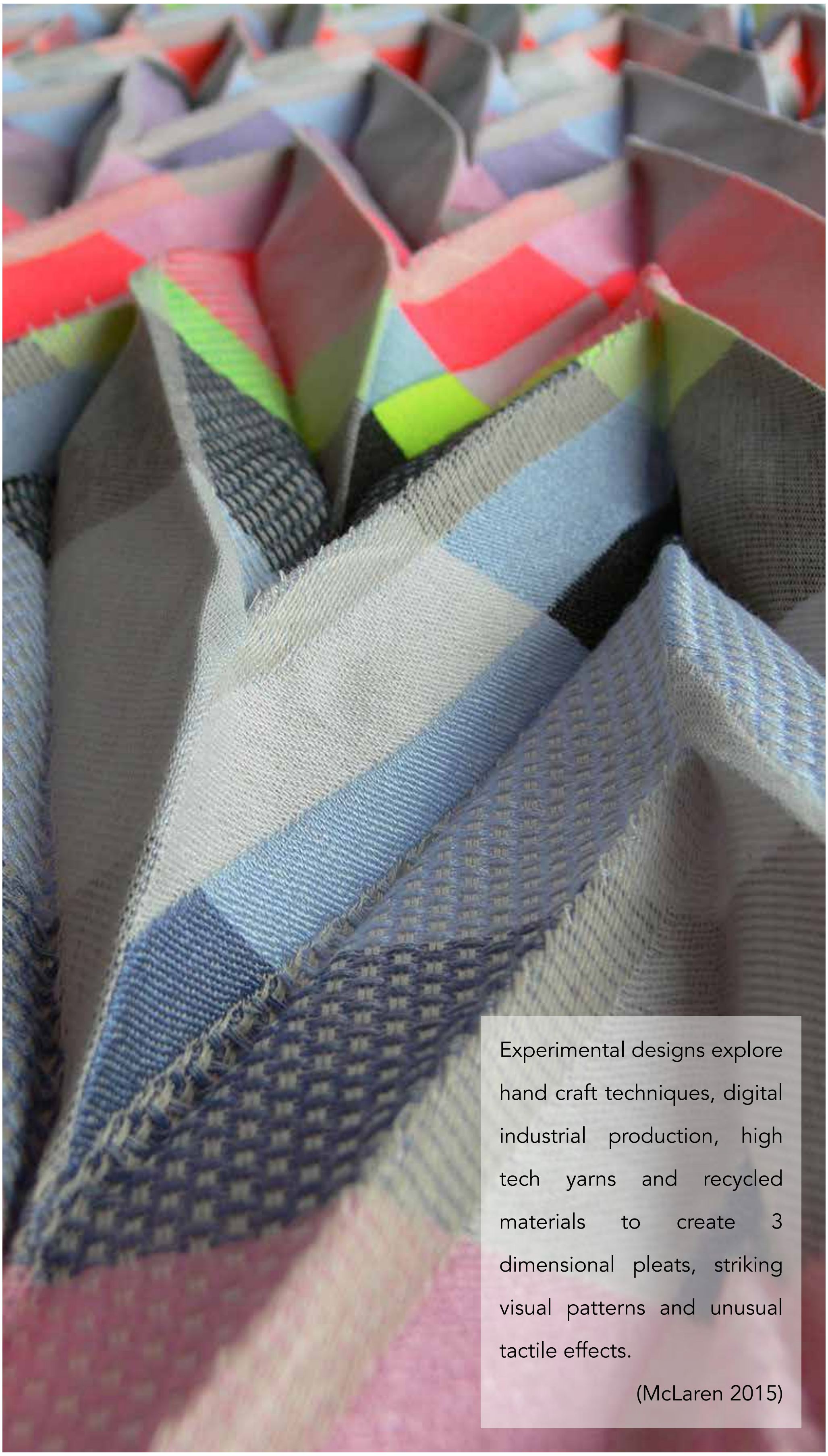
4.4.1 Industrial 3D Weaving

To date, commercial and academic research into 3D weaving has chiefly concentrated on architectural and engineering applications, with a focus on the production of composites, shaped shells and spacer fabrics, using advanced materials such as aramid and carbon fibres (see Shape3 c.2007 (commercial) and Zheng, Li, Jing & Ou 2013; Behere & Mishra 2008 (academic research)). Tubular construction techniques also have numerous medical applications, such as the production of prostheses (see Andersen 2005). The benefits of 3D weaving in these contexts include: strength, delamination (splitting/separation) resistance, seamlessness and dimensional flexibility (Bilsik 2012; Kaufmann 2012; Behere & Mishra 2008).

4.4.2 Craft Construction Techniques

Innovative shaped woven fabrics are being produced in the craft realm by practitioners including Angharad McLaren (Figure 4.7) and Philippa Brock, who describes herself as a "woven textile design engineer" (Hemmings 2012: 65). Both practitioners demonstrate an idiosyncratic approach to yarn and structure manipulation, using traditional and advanced fibres and technologies, to create dynamic 3D fabric forms. In her book 'Weaving Textiles That Shape Themselves', Richards describes the process as requiring "a deep, intuitive sense that goes beyond theoretical knowledge." (2012: 11).

Whilst McLaren and Brock produce highly structural 3D pieces featuring pleats and folds, Reiko Sudo's Nuno Corporation has used yarn manipulation techniques to create softer, more fluid effects. Using combinations of stiff, soft and highly twisted yarns , puckered effects and "crinkled texture" (Nuno c.2018) are produced, resulting in highly



> Experimental designs explore hand craft techniques, digital industrial production, high tech yarns and recycled materials to create 3 dimensional pleats, striking visual patterns and unusual tactile effects.
>
> (McLaren 2015)

Figure 4.7: Neon Shibori Pleats (2015) by Angharad McLaren

elastic fabrics (see for example Futsu Crisscross, 2008 (Cooper Hewitt c.2017)). In particular they have worked with Kibiso, a form of silk waste, which is usually disposed of as it is too rough to be spun or woven industrially[2]. Initially, Nuno's Kibiso fabrics were exclusively woven by hand, but more recently they have "refined kibiso down to a thickness that allows automatic machine looming" (Nuno c.2018) – making the transition from hand crafted to industrially crafted textiles.

These 3D textiles (surface texture to structural form) are of biaxial construction (which can combine tubular and layered construction techniques), transforming from 2D to 3D textile when removed from the loom and finished. Finishing often takes the form of washing and/or steaming, which triggers yarn relaxation, movement or shrinking, to generate the 3D form (see Figure 4.8). The results vary from subtle to dramatic dependent on weave structure, yarn properties, yarn combination and cloth density; the numerous variables can make the approach unpredictable.

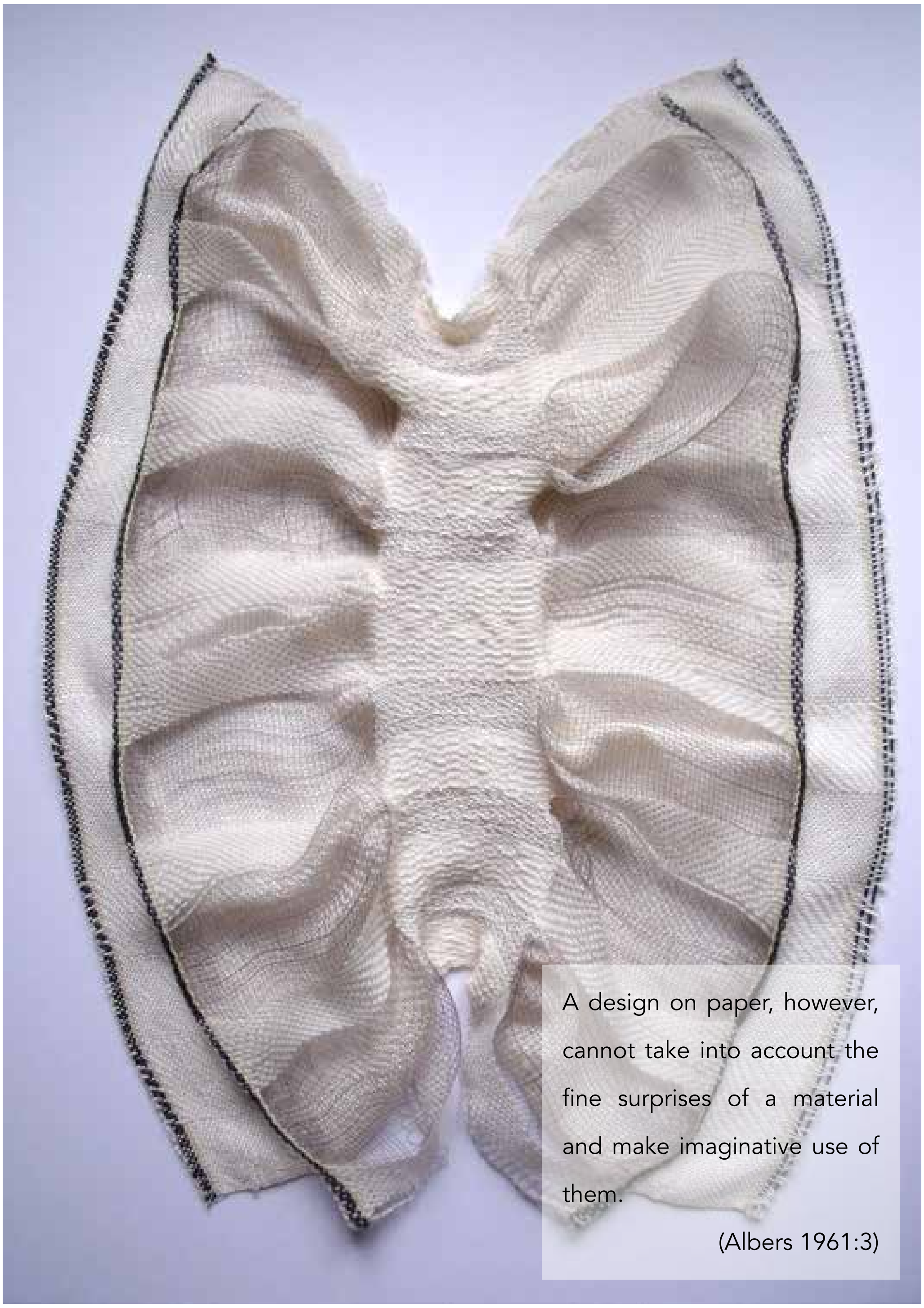
Textile designers have employed these techniques to generate diverse Jacquard and hand woven effects applied to fashion and interior accessories and textiles (examples include Aleksandra Gaca's Slumber Shawl and acoustic fabrics (2016), Nuno Corporation's Kibiso accessories collection (c.2018) and Signe Rand Ebbesen's interior and fashion fabrics (2015)). These (aforementioned) experimental 2D/3D textiles demonstrate the potential for a different approach to garment shaping and fitting.

4.5 3D Woven Textiles in Contemporary Fashion

From traditional garments such as the iconic peplum and the kilt to contemporary haute couture fashion, pleated textiles have been both an aesthetic and functional feature; controlling fullness, facilitating freedom of movement, and creating structural and fluid silhouettes. Although applied to woven fabrics during garment make-up, most commonly through folding, stitching and pressing, advances in technology and materials are facilitating increasingly innovative and complex 3D folded and structural forms. At the forefront of innovations in woven shaped textiles in fashion is Issey Miyake.

---

[2] Kibiso is the coarse outer layer of the silk cocoon. For a detailed explanation of the processing of Kibiso see Brown & McQuaid 2016.



> A design on paper, however, cannot take into account the fine surprises of a material and make imaginative use of them.
>
> (Albers 1961:3)

Figure 4.8: Monofilament, Silk and Lycra Pleat (2010) by Anna Piper
Photograph by Anna Piper

> […] the Japanese designers are able to define and create their original designs by challenging the usual method of construction and traditional logic of clothes.
>
> (Bueger in Au, Taylor & Newton. 2003: 19)

At the centre of Issey Miyake's ethos is simplicity, functionality and movement, a "co-existence of the fabric and the body" (Benaim 1997: 12) (Section 6.4.2). Adopting a "simultaneous design approach" (Townsend & Goulding 2011: 308) (designing textile and garment), Miyake has always focused on the creative possibilities of technology. Over recent years, his Director of Womenswear Yoshiyuki Miyamae has developed a new 3D Stretch Seam woven textile/garment concept, fully launched for Spring/Summer 2015. The fabrics constitute a "new kind of woven fabric", constructed from cotton and polyester, which contract into 3D structures when exposed to steam (Dezeen 2014). The 3D woven textiles are constructed into soft semi-structured garments with body and bounce. An extension of this concept is Baked Stretch (released in 2016). An oversized 2D woven garment is over-printed with a heat reactive adhesive that expands and manipulates the cloth when baked (Dezeen 2016). The two stretch concepts build upon Miyake's established Pleats Please (Figure 4.9) and A-POC collections, with 2D textiles transforming into 3D through the manipulation of textile properties[3].

The "a piece of cloth" (Issey Miyake Inc. 2016) principal that underpins these collections is evident in their unifying signature look – body-responsive garments, with the shape of the garment defined by the body and its movements (Townsend & Goulding 2011)[4]. All-over application of 3D pattern in various forms (pleats, waves etc.) is used to great functional and visual effect throughout Miyake's collections. However, Miyake is yet to exploit the selective and seamless placement weave structures, fibres and 3D shaping within a single garment to integrally shape or 'tailor' elements of woven garments.

---

[3] In the case of Pleats Please and Baked Stretch the 'finishing' treatment (pleating process and application of adhesive) are applied to the garment rather than the textile before cutting.

[4] Townsend and Goulding define a sculptural garment as:

- a garment shape that works with the natural body shape
- requiring a fluid textile with good draping properties
- the impact of the body is evident; the shape of the garment is defined by the form.

(2011: 295)

> [...] the aim is to put forth the beauty that can be achieved with just a "piece of cloth" [...]
>
> (Issey Miyake Inc. 2016)

Figure 4.9: 'Le Smoking' Pleated Polyester Jacket (c.1990) by Issey Miyake
Photograph by Anna Piper

4.6 Woven Textiles and Garment Construction

This section provides a short overview of woven textile construction (Section 4.6.1) and the inherent properties that determine the integral shaping capabilities of woven fabrics (Section 4.6.2). In doing so, it identifies the difficulties associated with integrally shaping woven textiles and garments (Section 4.6.3), which have arguably limited the development and application of fully-fashioned and single-piece garment weaving in commercial fashion.

Comparisons are made with the characteristics and construction of knitted textiles and garments – as a more established exponent of fully-fashioned and single-piece garment construction, it provides a platform for production process development. However, the fundamental differences between knitted and woven construction necessitate an alternative approach to garment design and shaping to exploit the unique qualities of woven textiles (such as stability, fineness and compactness (Section 4.6.3)). The traditional woven construction techniques and principles on which CPW is based are introduced in Sections 4.6.4 and 4.6.5; details of their testing, development and application are described in Chapter 7.

4.6.1 The Anatomy of Woven Textile

Constructed from intersecting lengths of yarn (the warp and weft), using a warp of predetermined and continuous width, woven textiles are predominantly constructed as rectangular lengths of fabric; with the dimensions of the loom determining the maximum width of the cloth (Burnham 1973).

The warp refers to the vertical yarns that, during weaving, are attached to the loom under tension. The warp yarns (known as ends) are lifted and lowered in sequence allowing the weft yarn (known as a pick) to be inserted and trapped between the warp at 90° (Figure 4.10). The weft interlaces with the warp by going over and under the warp ends; the order in which the warp ends are lifted determines the fabric structure[5].

The elementary weave structures (or simple structures) - plain, twill and satin (Figure. 4.11) – are the building blocks of woven fabric composition; constructed using a single warp and weft, in each unit (weave repeat) the warp and weft have a single point of interlacement (Ng & Zhou 2013). It is from these elementary structures that most other weave structures and common woven fabrics derive (Corbman 1983); variations in yarn, density and threading influence fabric appearance and properties.

---

[5] For further information on the principles of woven textile construction see Briggs-Goode & Townsend Eds. 2011; Wilson 2001; Corbman 1983.

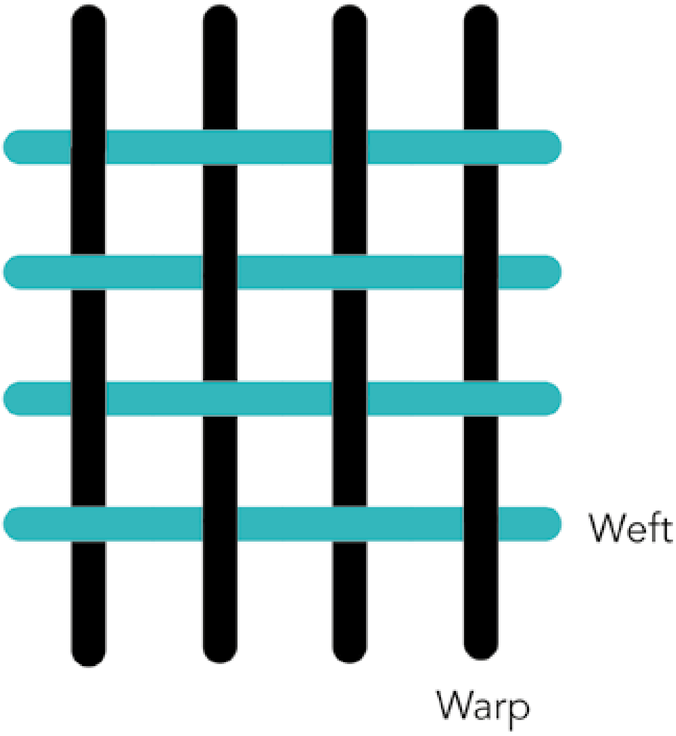


Figure 4.10: Anatomy of a Woven Textile (2016)
Illustration by Anna Piper

4.6.2 Woven Textile Construction: Properties and Characteristics

Stretch and stability: unless specifically woven with a stretch/elasticated yarn, woven fabrics have limited inherent stretch (Thomas 2009). This is due to their interlaced structure (described above). When force is applied across the width or length of a woven fabric a small amount of structural extension may be achieved as the undulations of the interlacement (the crimp) are flattened, however, greater extension can be achieved across the bias (Watkins & Dunne 2015). Between 3-5% stretch can be attributed to the flattening of the warp and weft, in contrast, a plain knitted textile can stretch 15-20% simply through loop deformation (the flattening of the stitches) (Cooke 2011). Some stretch can be achieved through yarn extension; the level of this stretch is dependent on fabric composition and construction. The lack of inherent stretch in most woven fabrics results in good dimensional stability[6]. The relative tightness and compactness of the interlaced structure limits deformation. Once finished, and the fibres are relaxed, most woven fabric experience minimal shrinkage.

[6] Dimensional stability is a fabric's resistance to permanent deformation

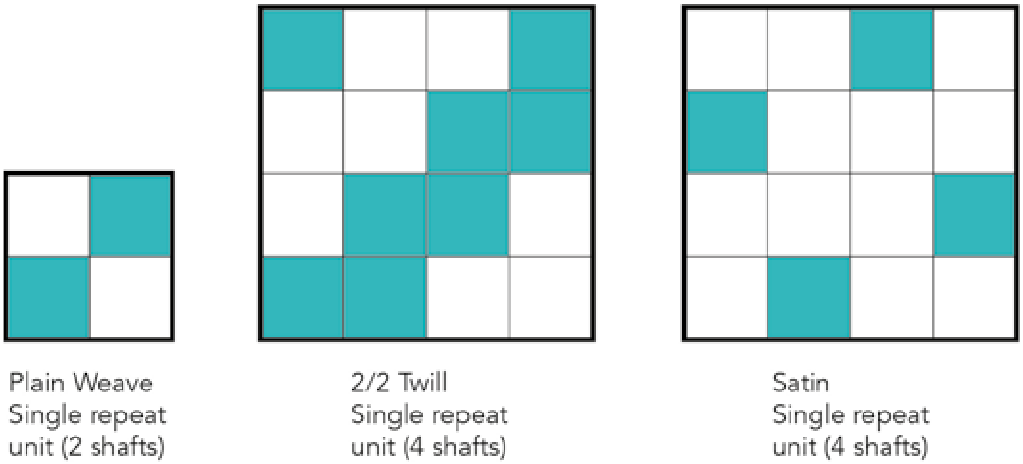


Figure 4.11: Elementary Weave Structures (2016)
Illustration by Anna Piper

Creasing and compression: the dimensional stability and compactness of most woven fabrics gives them the ability to hold structure and form, such as pleats and darts. Folding or creasing a textile bends the yarn, affecting the internal molecules of the fibre; molecules on the outer side of the fold are extended, whilst the molecules on the inner side are compressed. Over time this compression and extension can result in the collapse of the fibres' molecular structure, leading to a permanent fold or crease (Cooke 2011); this can be enhanced by the use of thermoplastic fibres such as polyester and nylon (Corbman 1983). The thickness of fabric and fibre type affect the fabric's ability to accept or resist creasing, folding or pleating. Tight structures and finer fabrics are generally best suited to holding a pleat and, therefore, are also susceptible to creasing (Cooke 2011). The relative rigidity of the yarns within a woven structure allows the yarns (and therefore the fibres) to fold sharply. In contrast, the looser, thicker nature of knitted construction usually results in them rolling or bending rather than folding; as such they have greater crease resistance (Ibid).

The properties of knitted fabrics and garments – their inherent stretch, thickness, yarn mobility and dimensional instability that result from their looped construction (Figure 4.12) – facilitates excellent drape and form-fitting capabilities that contribute to comfort and fit. It is these stretch and form-fitting qualities and garment characteristics that most of the significant academic research into fully-fashioned garment weaving has sought to recreate (see Wang 2011; Wang et al. 2009; Ng et al. 2010 & 2007; Singh Sawhney 1972). This is perhaps due to the limited opportunities for integral shaping afforded by weaving's continuous warp width and interlaced construction (Section 4.6.3).

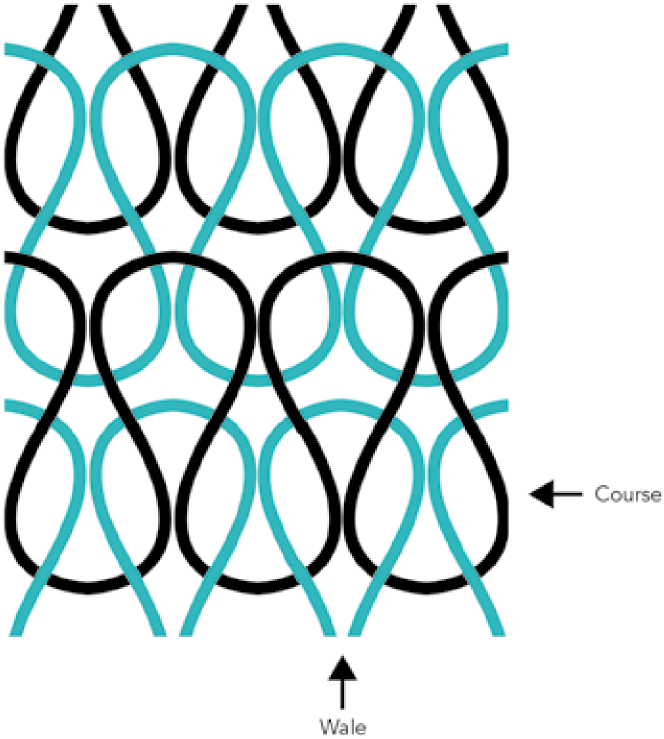


Figure 4.10: Anatomy of a Knitted Textile (2016)
Illustration by Anna Piper

In response, this research aims instead to capitalise on the inherent qualities of woven textiles (stability, fineness and compactness), applying them to a new type of woven garment construction that does not rely solely on stretch using elastomeric yarns; instead pursuing the opportunities of integral shaping through permanent shrink and the application of cellular structures, using and adapting traditional weaving techniques (Section 4.6.4).

4.6.3 Woven Textile Construction: Fashioning and Shaping Methods

> It is unlikely that fully fashioned woven garments will ever be as flexible and as controllable as 'whole garment' knitting technology.
>
> (Thomas 2009: 151)

The unchanging warp width, dimensional stability and compactness of most woven fabrics limits complex shaping possibilities. Conversely, the looped construction of knitted fabrics is suited to the production of variable shaped components and integrally shaped garments. A number of methods are used in fully-fashioned and integral garment knitting – increasing and decreasing stitches, altering the knit structure and

Technique	Method	Purpose
• Course Shaping	• Holding and reintroducing stitches either at the end(s) of or within a course	• Generation of 2D or 3D shaping
• Narrowing	• Combing adjacent loops at the selvedge reducing stitches/loops in the next course	• Progressive narrowing of the fabric
• Running-on	• Knitting from/on the edges of a knitted piece of fabric by placing the course or selvedge on the machine needles and knitting	• Creating connected fully-fashioned components
• Stitch Length	• Shortening/tightening a stitch to narrow the fabric and extending the length/ loosening to widen	• Graduated shaping to alter the tightness or elasticity of the fabric
• Wale Shaping	• Increasing or reducing wales within a flat piece or tube	• Generation of 2D or 3D shaping
• Widening	• Creating a space adjacent to the edge loop creating a tuck loop in the next course	• Progressive widening of the fabric

Table 4.1: Knitted Fashioning and Integral Shaping Methods[7]

changing the stitch length (Ray 2012; Spencer 2001; Brackenbury 1992) (Table 4.1). These shaping techniques are structural and do not rely (exclusively) on the properties of the yarn.

The ability to increase or decrease the width of a woven fabric during weaving is hindered by the use of individual warp yarns which are attached to the loom under tension. Once threaded and tied onto the loom, the warp is held in a fixed position, with the spacing between the individual threads regulated by the reed. The reed determines both the width of the warp and the density of the fabric (Figure 4.13). Whilst progressive edge shaping can be achieved (in hand and hybrid weaving) by inserting the weft into selected sections of the warp, the width of the warp is not

[7] Shaping method sources: Spencer 2001; Brackenbury 1992

Figure 4.13: The Reed Determining the Width and Density of the Warp (2017)
Photograph by Anna Piper

diminished (leaving unusable and unwoven waste yarns) unless the warp threads are cut away (Figure 4.14). Not only does the cutting of warp threads generate waste, but it also precludes any subsequent increase in the width of the cloth.

Integral shaping within the 'body' of the cloth involves a further level of complexity. Stretch or shrinking yarns can be selectively positioned within the width of the cloth, or used across the full width of warp, in conjunction with weave structures that enable or inhibit shinking and contraction. However, the impact of these yarns and structures is not discernible until the warp tension is released, and the fabric is removed from the loom and finished (washed or steamed). As such, results can be unpredictable and significant testing and experimentation is required to effectively calculate and control the degree of shaping.

This method of manipulating and controlling fibre/yarn characteristics to 'self-shape' woven fabrics is adopted in this research to integrally shape the woven garments (Sections 7.5, 7.7 and 7.9). The principles of 'self-shaping' are outlined in Section 4.6.5.

Figure 4.14: Progressive Edge Shaping (2018)
Photograph by Anna Piper

4.6.4 Woven Textile Construction: Techniques

Block threading and single and double cloth weaving are widely used techniques for producing woven fabrics. A block draft (or block threading) consists of units of warp threads with shafts allocated to specific blocks, to facilitate the weaving of different structures in (isolated) sections of the cloth (Figure 4.15)[8]. In multiple cloth weaving a number of warps are threaded and lay on top of each other allowing multiple fabrics

[8] The use of block threading applies to hand weaving only, as the Jacquard looms (Power Loom and TC2) use single-end control (Section 7.2.1).

Figure 4.15: Block Threading Facilitating the Panelling of Weave Structures (2018)
Photograph by Anna Piper

to be woven concurrently[9]; using this technique, complex patterns, double-sided and tubular fabrics can be generated (see Alderman 2008 for detailed explanations of block threading, single and double cloth weaving techniques).

[9] **Double cloth:** double cloth construction uses two warps with specific shafts allocated to each to create two layers. The layers can be woven independently using two (or more) wefts, woven as a tube by using the same weft throughout, or the cloths can intersect and be joined or 'stitched' together by lowering or lifting selected shafts from one cloth when weaving the other. **Single cloth:** a single cloth construction uses one warp.

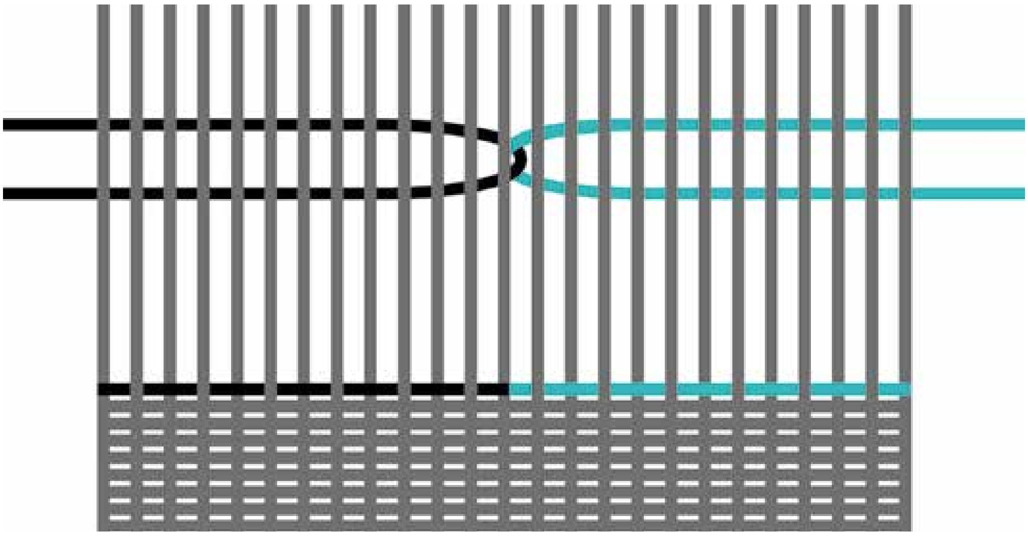


Figure 4.16: Clasped Weft Technique (2018)
Illustration by Anna Piper

The design and production strategy developed by this research combines single cloth (using one warp) and double cloth (using two warps) weaving to produce tubular and quilted components, and integrated seams. Block threading is applied in hand weaving to facilitate the positioning of functional weave structures and panels (Sections 7.5, 7.6 and 7.8). In addition, the decorative tapestry weaving technique 'Clasped Weft' (or Interlocking Weft Threads (Redman 1976)), whereby two weft yarns are interlinked within a single row (or pick) (Figure 4.16), is used to selectively position yarns to integrally shape garments or to differentiate between pattern pieces (see hand woven trouser construction in Section 7.5.1 and hybrid top construction in 7.9.1).

4.6.5 Woven Textile Construction: Self-shaping Principles

Three principal weaving elements and their interrelationships are identified as contributing to the ability to 'self-shape' and introduce three-dimensional form into woven fabrics, based on the selection and manipulation of: weave structure, yarn type and warp/weft density.

'Active' yarns alter the fabric structure by shrinking or contracting in response to finishing treatments (for example washing or steaming); the extent of the change depends upon the variables outlined above. They are often referred to as unstable or unbalanced - as having 'energy' - and are categorised as elastic, overspun, fulling/felting or shrinking (Dalgaard 2012; Richards 2012). In contrast, 'passive' yarns are stable, balanced yarns that remain structurally unchanged when finished. When combined with 'active' yarns, 'passive' yarns are manipulated, creating texture or 3D form. They can also be used and positioned to inhibit movement and textile manipulation.

A range of properties offered by different types of 'active' yarns have been utilised in this research to develop integral shaping strategies and contrasting textile qualities (Section 7.3).

4.7 Composite Garment Weaving to Composite Pattern Weaving

This research began with the aim of producing integrally shaped, seamless 3D woven garments that required no cutting and stitching once removed from the loom. In order to achieve this, a TC2 digital Jacquard sample loom was procured by Nottingham Trent University in 2015 for use alongside existing hand and digital equipment. However, the installation of the loom took longer than anticipated and the TC2 was not available for use until November 2017. This delay enabled a shift in the research focus, with the decision made in the summer of 2017 (following the completion of the Component Construction phase) to concentrate on the development of the CPW system[10].

In making the decision to move towards the production of composite patterns rather than seamless composite garments, it was recognised that the CPW system has the potential for greater flexibility and wider application across the commercial woven garment industry. Although complex, CPW is less restrictive in terms of the types/ styles of garments that can be produced, whilst adhering to the original principles of minimising material consumption and eliminating cutting waste. In addition, there is scope for this approach to be integrated with existing ZWPC methods; facilitating the production of garments that contain multiple fabric qualities along with engineered patterns and panelling to enhance garment functionality. The system has been developed and applied to the production of single-piece garment prototypes (the t-shirt and dress), more conventional multiple piece garments (trousers, jacket and coat), as well as a composite long-sleeved top.

---

[10] Due to the delays in loom installation and the complexities of assimilating integral shaping into composite garments, it was no longer deemed feasible to do this in the remaining time. Composite garment prototypes are designed specifically for the loom on which they are to be produced. The type of warp yarn, lifting mechanism and warp width are critical factors in the design process.

4.8 Technical Context: Chapter Conclusion

This chapter has outlined the context in which the CPW system is situated, in doing so it establishes the technical and design limitations of existing research into fully-fashioned, single-piece and composite garment weaving. Whilst it has exposed a dearth of studies exploring design-led approaches to woven garment production for fashion applications in recent decades, during the course of this research (2013-2018) a number of designers (McQuillan 2018; Manonik 2017; friends of light 2016; Lefferts 2015) have recognised the sustainable potential of fully-fashioned and composite garment weaving with techniques being developed to minimise material production, cutting waste and off-loom garment stitching/construction.

By considering and comparing knitted and woven textile construction and characteristics, the chapter has highlighted the complexities of fashioning and integrally shaping woven fabrics and garments directly on the loom. It has also exposed opportunities for captialising on the stability, compactness and fineness of woven textiles, and the ability to assimilate multiple weave structures seamlessly to integrate and strategically position integral shaping and functional panelling to respond to the physical needs of the wearer (Section 6.3).

4.9 References

ALBERS, A. (1961). *Albers: On Designing*. Connecticut: Wesleyan University Press.

ALDERMAN, S. (2008). *Mastering Weave Structures: Transforming Ideas into Great Cloth*. Loveland: Interweave Press Inc.

ANDERSEN, K, S. (2005). 'Seamless Textiles with Inherent Shape'. (PhD Thesis) North Carolina: North Carolina State University. Available at: http://repository.lib.ncsu.edu/ir/handle/1840.16/3810. Accessed: 01 August 2014.

AU, S. TAYLOR, G. & NEWTON, E. (2003). 'Grounded Design Theory of Japanese Fashion Designers'. *The Design Journal*. 6(3). pp. 3-23.

BENAIM, L. (1997). *Fashion Memoir: Issey Miyake*. London: Thames & Hudson.

BEHERA, B, K. & MISHRA, R. (2008). '3-Dimensional Weaving'. *Indian Journal of Fibre & Textile Research*. 33. pp. 274–287.

BILISIK, K. (2012). 'Multiaxis Three-Dimensional Weaving for Composites: A Review'. *Textile Research Journal*. 82(7). pp. 725–743.

BRACKENBURY, T. (1992). *Knitted Clothing Technology*. London: BSP Professional.

BRAMALL, S. (2005). 'Key Trends in Sportswear Design'. In: SHISHOO, R. (Ed.). (2005). *Textiles in Sport*. Cambridge: Woodhead Publishing in Textiles. pp. 25-43.

BRIGGS-GOODE, A. & TOWNSEND, K. (Eds.). (2011). *Textile Design: Principles, Advances and Applications*. Oxford: Woodhead Publishing.

BROWN, S. & MCQUAID, M. (2016). *Scraps: Fashion, Textiles, and Creative Reuse*. New York: Cooper Hewitt

BURNHAM, D, K. (1973). *Cut My Cote*. Toronto: Royal Ontario Museum.

COLCHESTER, C. (2007). *Textiles Today: A Global Survey of Trends and Traditions*. London: Thames & Hudson.

COOKE, B. (2011). 'The Physical Properties of Weft Knitted Structures'. In: AU, K. F. (Ed). (2011). *Advances in Knitting Technology*. Cambridge: Woodhead Publishing. pp. 37-47.

COOPER HEWITT. (c.2017). 'Objects Involving Nuno Corporation as "Manufacturer". *Cooper Hewitt, Smithsonian Design Museum*. Available at: https://collection.cooperhewitt.org/people/18045705/ objects/ manufacturer/. Accessed: 29 July 2018.

CORBMAN, B, P. (1983). *Textiles: Fiber to Fabric.* (6th Edition). London: McGraw-Hill.

DALGAARD, L. (2012). *Magical Materials to Weave: Blending Traditional & Innovative Yarns*. Translated by Ann Richards. Vermont: Trafalgar Square Books.

DE KLEE, K. (2016). 'Friends of Light: Handwoven Jackets From New York'. *Design Indaba.* Available at: http://www.designindaba.com /articles/point-view/friends-light-handwoven-jackets-new-york. Accessed: 27 July 2018.

DEZEEN. 2016. 'Issey Miyake Bakes Fabric to Pleat Spring Summer 2016 Garments, 8th January 2016'. *Deezen*. Available at: http://www.dezeen.com /2016/01/08/spring-summer-2016-fashion-collection-issey-miyake/ Accessed: 13 July 2016.

DEZEEN. 2014. 'Issey Miyake's focus is "being innovative with technology" says head of womenswear, 12th November 2014'. *Dezeen*. Available at: http://www.dezeen.com/2014/11/12/issey-miya ke-yoshiyuki- miyamae-interview-3d-stretch-seam-fashion-technology/. Accessed: 09 September 2015.

GACA, A. (2016). 'Aleksandra Gaca, Collections'. *Aleksandra Gaca*. Available at: https://www.aleksandragaca.eu/collections. Accessed: 27 July 2018.

HEMMINGS, J. (2012). *Warp and Weft: Woven Textiles in Fashion, Art and Interiors*. London: A & C Black Publishers Ltd.

ISSEY MIYAKE. (2016). 'Issey Miyake: Autumn Winter 2016 Video'. *Issey Miyake Inc*. Available at: http://www.isseymiyake.com/en/ brands/issey_miyake.html. Accessed: 13 July 2016.

JAYARAMAN, S. & PARK, S. (2001). *Full-fashioned Garment with Sleeves Having Intelligence Capability* (Patent). Available at: http://www.google.com/patents/ US6315009. Accessed: 07 January 2016.

JAYARAMAN, S. PARK, S. & RAJAMANICKAM, R. (2000). *Full-fashioned Weaving Process for Production of a Woven Garment with Intelligence Capability* (Patent). Available at: http://www.google.co.uk/ patents/US6145551. Accessed: 07 January 2016.

KAUFMANN, J. (2012). 'An Introduction to 3-D Weaving''. T*extile World*. Jul/Aug 2012.

KUUSK, K. (2016). 'Smart Textiles for Wellbeing'. Tekstiililehti. Available at: http://www.tekstiililehti.fi/fi/ajankohtaista/smart+textiles+for+wellbeing+may+2016/. Accessed: 26 July 2018.

LEE, Y. (2016). 'Seaming, Writing, and Making Strange: Between Material and Text'. *Studies in Material Thinking*. Vol. 14. Experience/Materiality/ Articulation'. Available at: https://materialthinking.org/papers/224. Accessed: 16 June 2016.

LEFFERTS, J. (2015). 'Gestalt Process'. *T:W:O by Jacqueline Lefferts*. Available at: http://www.jacquelinelefferts.com/#/gestaltprocess/. Accessed: 06 November 2018.

MANONIK. (2017). 'Manonik, Principles'. *Manonik*. Available at: http://www.manonik.com/about/. Accessed: 26 July 2018.

MCLAREN, A. (2015). 'Angharad McLaren Textiles'. *Angharad McLaren*. Available at: http://www.angharadmclaren.co.uk/#/angharad-mclaren-textiles/. 29 July 2018.

NG, M, C, F. & ZHOU, J. (2013). *Innovative Jacquard Textile Design Using Digital Technologies*. Cambridge: Woodhead Publishing Limited. Excerpt available at: https://bit.ly/2LUgarw. Accessed: 28-May-2014.

NG, M, C, F. WANG, Z. HU, J. SZETO, Y, C. (2010). 'Shapeable Stretch Textiles via Compound Weaves for Seamless Woven Fashion'. *Textile Research Journal*. 80(12) pp.1191–1200.

NG, M. C. F. HU, J. SZETO, Y, C. & WANG, Z. (2007). 'Integrated Design of Seamless Fashion in Woven Textile with Multilayer"'. *Research Journal of Textile and Apparel* .11(2). pp. 67–74.

NG, M. C. F. (1999). 'A Study of Techniques Processes and Procedures Enabling Creation of Seamless Fashion Towards Innovative Ends'. *Research Journal of Textile and Apparel*. 3(2). pp41-52.

NIKE. (2014). 'NIKE, Inc: The Most Technical First Layer in Sport. Nike Hyperwarm Flex'. *Nike Inc*. Available at: http://nikeinc.com/news/the-most-technical-first-layer-in-sport-nike-hyperwarm-flex#/inline/33747. Accessed: 15 October 2015.

NOTTINGHAM TRENT UNIVERSITY. (2015). 'Research Group Develops Gloves Which Relieve Pain for Raynaulds Sufferers'. *Nottingham Trent University*. Available at: https://www.ntu.ac.uk/about-us/news/news-articles/2015/01/research-group-develops-gloves-which-relieve-pain-for-raynauds-sufferers. Accessed: 27 July 2018.

NUNO. (c.2018). 'Kibiso Story'. *Nuno Online*. Available at: https://www.nunoonline.com/pages/about-kibiso. Accessed: 29 July 2018.

OSBORNE, E, F. (2009). *Weaving Process for Production of a Full Fashioned Woven Stretch Garment with Load Carriage Capability* (Patent). Available at: https://bit.ly/2mKyXdI. Accessed: 07 January 2016.

RAND EBBESEN, S. (2015). 'Signe Rand Ebbessen, Woven Textile Designer'. S*igne Rand Ebbessen*. Available at: http://signerandebbesen.com/woven-textile-designer/. Accessed: 27 July 2018.

RAY, S, C. (2012). *Fundamentals and Advances in Knitting Technology*. Cambridge: Woodhead Publishing Limited.

REDMAN, J. (1976). *Frame-loom Weaving*. New York: Van Nostrand Reinhold Ltd.

RICHARDS, A. (2012). *Weaving Textiles That Shape Themselves*. Ramsbury: The Crowood Press Ltd.

RUDGE, G. (2001). 'A Piece of Cloth'. *Crafts*. Nov/Dec 2001. 22–25.

SANTONI. (c.2014). 'Santoni Seamless'. *Santoni*. Available at: http://www.santoni.cn/en/seamless. Accessed: 16 October 2014.

SHAPE 3. (c.2007). 'Shape Weaving: Weaving of 3D Shells and 3D Tubes'. *Shape 3 Innovative Textiltechnik GmbH*. Available at: http://www.shape3.com/Frameset_Shape3.htm. Accessed: 20 November 2013.

SHIMA SEIKI. (2015).'WHOLEGARMENT'. *Shima Seiki*. Available at: http://www.shimaseiki.com/wholegarment/. Accessed: 03-Feb-2016.

SINGH SAWHNEY, A, P. (1972). 'Apparel Weaving – A New Concept'. *Textile Industries*. Dec 1972. pp.50-56.

SPENCER, D, J. (2001). *Knitting Technology*. (3rd Edition). Oxford: Pergamon.

TEN BHÖMER. (2016). 'Vigour'. *Martijin ten Bhömer.* Available at: https://www.mtbhomer.com/portfolio/vigour/. Accessed: 26 July 2018.

TEXTRONICS. (2016). 'Textronics Energy-activated Fabrics'. *Textronics Inc*. Available at: http://www.textronicsinc.com/. Accessed: 17 August 2016.

TEXTILES INTELLIGENCE. (2018). 'Seamless Knitting and Stitch-free Seaming in Performance Apparel'. *Innovation in Textiles*. Available at: https://www.innovationintextiles.com/seamless-knitting-and-stitchfree-seaming-in-performance-apparel/. Accessed: 26 July 2018.

THOMAS, L. (2009). 'Woven Structures and Their Impact in the Function and Performance of Smart Clothing'. In: MCCANN, J. & BRYSON, D. (Eds.). (2009) S*mart Clothes and Wearable Technology*. Cambridge: Woodhead Publishing in Textiles. pp.131–155.

TOWNSEND, K. & GOULDING, R. (2011). 'The Interaction of Two and Three Dimensional Design in Textiles and Fashion'. In: BRIGGS-GOODE, A. & TOWNSEND, K. (Eds.). (2011). *Textile Design: Principles, Advances and Applications*. Oxford: Woodhead Publishing. pp.288-322.

VAN DONGEN, P. (2016). 'Vigour'. *Pauline van Dongen*. Available at: http://www.paulinevandongen.nl/project/vigour/. Accessed: 26 July 2018.

VAN REES, H. (2014). 'Tweedlapse'. *Vimeo*. Available at: https://vimeo.com/98527123?from=outro-embed. Accessed: 16 June 2016.

VITRA DESIGN MUSEUM. (2001). *A-POC Making: Issey Miyake and Dai Fujiwara* (Exhibition Catalogue). Berlin: Vitra Design Museum.

WANG, X. (2011). 'A Study on Silk Full-Fashioned Weaving for Women's Wear'. *Advanced Materials Research* .175. pp.1035–1039.

WANG, X. NG, M, C, F. HU, J. & SZETO, Y, C.. (2009). 'Shapeable Stretch Textiles via Simple Weaves for Seamless Woven Fashion'. *Textile Research Journal*. 79(18). pp.1715–1724.

WATKINS, S, M. & DUNNE, L, E. (2015). *Functional Clothing Design: From Sportswear to Spacesuits.* London: Bloomsbury.

WILSON, J. (2001). *Handbook of Textile Design: Principles, Processes and Practice*. Cambridge: Woodhead Publishing Ltd.

ZHENG, T. LI S. JING, S. & OU, Y. (2013). 'Designing of 3D Woven Integrated T-Joint Tube'. *Textile Research Journal*. 83(11). pp.1143-1155.

5 Sustainability:
A Multi-method Lifecycle Approach

5 Sustainability:

A Multi-method Lifecycle Approach

5.1 Sustainability Aim

To establish methods of minimising cutting waste and reducing material production in woven garment design and construction, through the development of garment prototypes that explore form, function and multi-functionality as design imperatives.

5.2 Sustainability Aim: Chapter Overview

This chapter considers the sustainability debates that informed the development of Composite Pattern Weaving (CPW), with a particular focus on the key issues of pre- and post-consumer fashion and textile waste, and the existing strategies designed to manage and eliminate them. By analysing existing arguments, models and methodologies, and by reviewing my past approaches to sustainability I will determine the sustainability framework and criteria for the research (Section 5.3), as well as establishing the potential impacts of the work within the context of sustainable textile and fashion design and production.

5.3 Sustainability Framework: Principles and Priorities

Strategies to enhance sustainability and limit the environmental impact of clothing by minimising and managing waste and enhancing garment longevity rely upon the “right” decisions being made during the design process (DEFRA 2013a). These decisions relate to all aspects of design including material selection, garment styling and functionality, pattern cutting and construction methods. They encompass and influence the production, use and disposal phases of a garment’s lifecycle.

Figure 5.1: BA Final Collection: Tube-based Garments (2012) by Anna Piper
Photographs by Anna Piper

This section sets out the sustainability framework for this research. It details the specific criteria used to guide design decisions, develop designs and evaluate outcomes. It demonstrates how these principles were applied and contributed to development of CPW and the Transitional Design Methodology (Chapter 3), establishing the sustainable potential of this type of garment construction.

5.3.1 Sustainable Design Principles: Background

This research is an extension of my Undergraduate (2012) and Postgraduate (2013) research into the production of woven composite garments – garments constructed on and wearable from the loom. My Undergraduate project culminated in the production of a series of hand woven, tube-based tops and skirts (Figure 5.1). Lycra was used to gather and shape the woven tubes – the use of a combination of stiff and soft fibres achieved fullness. In contrast, the three garments produced during my Masters studies (a dress, jacket and top) (Figure 5.2) included no integral shaping[1]. Instead they concentrated on silhouette shaping and seam elimination; forming more complex functional garments incorporating sleeves, pockets and engineered patterning, all designed to minimise cutting, stitching and the production of waste.

[1] Both the hand and Jacquard woven garments are double-layered pieces with sealed edges and openings. They can be likened to "flat-packed garments" and "flat cutting" (Aldrich 2008: 131) - they have no darts or three-dimensional shaping. The garments have no structural integrity to support or hold form independently; the body is inserted between the layers to support the garment shape and give it form.

Figure 5.2: MA Final Collection (2013) by Anna Piper
Photographs by Anna Piper

Both projects were driven by a desire to address the wastefulness of woven production and of conventional pattern cutting/garment construction methods (Section 5.5). The garment construction and waste management methods established during my Postgraduate studies (listed below and illustrated in Figures 5.3 and 5.4) provided the starting point for the development of CPW techniques and processes, and were applied and extended throughout the research.

Useable warp waste: rather than minimising warp waste by weaving as much of it as possible (leaving short lengths of unusable yarn), longer lengths remain unwoven and are retained and integrated as weft yarns in subsequent designs.
Garment components: garments are designed with fold-over necklines and fold-in pockets to limit instances where sections of the warp are not utilised.
Single-fibre fabrics: mono-fibre yarns are used to produce fabrics and garments suitable for recycling. Rather than introducing additional yarn types, yarns are grouped creating pattern, texture and relief. This technique also utilises a significant proportion of the generated warp waste.

Figure 5.3: Folding Neckline to Maximise Warp Use (2013) by Anna Piper
Photographs by Anna Piper

Whilst the 'Single-fibre Fabrics' criterion continues to be important to me as a designer, I recognised that adhering rigidly to this principle could compromise garment functionality, as well as limiting the ability to explore the potential of CPW as a viable method of garment production and construction. As the integral shaping of garment components is intrinsic to the success of CPW and I was constrained to working with machines with predetermined warps[2], it quickly became clear that restricting all garments to single fibre composition was not feasible. As a result, the sustainability criteria for the selection of yarns was reviewed and classified as being 'imperative' or 'ideal' (Section 5.3.2).

Ultimately, although technical testing involved the production of samples incorporating multiple fibre types (Section 7.3), no mixed-fibre yarns were used in garment prototypes, and only one garment (Top #2) included multiple fibre types (Section 7.9).

[2] The method of construction also influenced yarn choice, particularly in relation to the warp. When using the hand loom, there are no constraints as the warp is designed and produced specifically for the garment being produced. However, when working with the TC2 hybrid loom or the digital Jacquard loom (in an academic setting), I had to work with the warp yarns that are already in use on the machines – in both cases 100% cotton.

Figure 5.4: Mono-fibre Fabrics: Stitch and Panel Collection (2013) by Anna Piper
Photographs by Anna Piper

5.3.2 Sustainable Design Principles: Imperatives and Ideals

This research adopts a multi-method lifecycle approach to garment design and production, with responsible and sustainable design practices integrated at all stages of the process; taking into consideration textile and garment production, use and disposal. Focussing on two specific areas – waste minimisation (Sections 5.6 – 5.9) and garment functionality (Section 5.8) – principles and priorities were established (Table 5.1).

Principle	Imperative	Ideal
• Produce garment patterns/lay-plans that eliminate cutting waste	✓	
• Minimise seams, cutting and stitching to limit material consumption	✓	
• Use mono-fibre yarns to produce textiles and garments suitable for recycling	✓	
• Produce single-fibre fabrics and garments suitable for recycling		✓
• Generate useable warp waste and utilise in the construction of subsequent designs		✓
• Design physically durable garments to withstand wear and tear through effective yarn and weave structure selection and application	✓	
• Design functionally durable garments that respond to the needs of the body for effective comfort and fit through textile composition, garment silhouette and adjustable design features	✓	
• Design aesthetically desirable garments by considering styling, colour application and fabric qualities (visual and tactile)	✓	

Table 5.1: Sustainability Principles and Priorities

Principles were classified as 'imperative' or 'ideal' to ensure adherence to the overarching sustainability and technical aims of the research, whilst demonstrating the future potential of CPW as an alternative (and more sustainable) approach to garment design and production (Section 5.3.1). These principles determined boundaries and criteria for design, presenting challenges and providing opportunities that 'shaped' both the garment prototypes and the design methodology (Section 3.3).

5.4 The Evolution of Fashion: Democratisation, Demand and Design

Past attitudes and approaches to the production, use and disposal of fashion and textiles are providing models for designers/researchers developing strategies to respond to and mitigate the unsustainability of the fashion system (see Global Fashion Conference 2018[3]). As designers seek to regain the valued status of textiles (Section 5.4.2), historical approaches to minimising waste, facilitating repair and resizing, and the cultivation of emotional connections inform and inspire new initiatives and innovations in sustainable fashion design. This is evident in the work of zero waste fashion designers Holly McQuillan and Timo Rissanen (Section 5.7), Amy Twigger Holroyd's 'Keep and Share' craft knitwear (2004-2014) (Twigger Holroyd 2017), and Christina Kim's use of hand woven sari fabric in her 'Life of Jamandi Project' (2002-2018) (Dosa c.2017) to name just a few.

This section provides a short overview of the significant historical and cultural events that have informed and necessitated the development of new sustainable approaches to design in contemporary fashion[4]. It briefly considers the role of key technological and economic factors in the changing value of textiles and the changing shape of woven fashion garments - specifically focusing on the transition from geometric shapes to tailored silhouettes and its impact on waste generation in the fashion system. Both are intrinsic to the sustainability (or unsustainability) of contemporary fashion; influencing consumer demand and behaviour, and propagating wasteful fashion design and production processes.

---

[3] The Global Fashion Conference 2018 What's Going On? A discourse on fashion, design and sustainability (31st October - 1st November 2018, London College of Fashion, University of the Arts London), considered sustainable fashion design models and strategies, focussed around the key themes of 'Nature and Culture' and 'Power and Society'. Speakers including Kate Fletcher, Otto Von Busch and Linda Grose, amongst others explored the "root causes of the problems we face"(Global Fashion Conference 2018) in the consumption, production and disposal of fashion, along with emerging and established approaches designed to address them (e.g. slow fashion, bio-fabrication, waste minimisation and co-design).

[4] Comprehensive studies of fashion history and development include Tortora 2015, Wilson 2003 and Burnham 1973.

5.4.1 Democratising Fashion: Technology, Economy and Culture

Fashionable dress is said to have originated in Europe towards the end of the Middle Ages (Tortora 2015; Wilson 2003). It was not until the 15th and 16th centuries, that "it began to seem shameful to wear outdated clothes" (Wilson 2003: 20). Until the Industrial Revolution, fashion was reserved for the rich – for those that could afford to discard clothing "simply because it had gone out of style" (Ibid).

In a detailed analysis of the relationship between technological innovation and fashion, Tortora describes the impact of mechanisation on the consumption and accessibility of clothing, stating:

> The textile machinery developed in the eighteenth and early nineteenth centuries made fashionable fabrics from which to cut and sew garments available in greater quantities at lower prices, making it possible for women of more modest means to wear the latest styles.
>
> (2015: 125)

The Industrial Revolution and the mass production of standardised garments incrementally led to the democratisation of fashion, and by the 1950s clothing was readily being purchased rather than being made at home (Black 2008). However, by the mid-1980s mass production began to fade (Bhardwaj & Fairhurst 2010). Bhardwaj and Fairhurst align this with an increase in fashion trends and changes in the supply chain, whereby retailers and consumers demand lower quality, cheaper clothes delivered at greater speed to respond to styles seen on the catwalk (Ibid) (Section 5.4.2). This has become all the more acute due to the speed, accessibility and prevalence of online marketing and retailing.

Mass produced styles have now been replaced by small collections of seasonal, trend-led and throwaway garments (Greenpeace 2016; Bhardwaj & Fairhurst 2010). This has culminated in a globalised fast fashion system of escalating consumption, ever-changing styles and ever-cheaper fashion, which both stimulates and satisfies consumer desire. This is reflected in Greenpeace's fashion consumption statistics:

While in 2002 sales of clothing were worth $1 trillion, this has risen to $1.8 trillion by 2015 – and is forecast to rise further to $2.1 trillion by 2025. This represents huge volumes of material - clothing production doubled from 2000 to 2014. The average person buys 60 percent more items of clothing and keeps them for about half as long as 15 years ago.

(Greenpeace 2016: 2)

5.4.2 The Changing Value of Fashion

Often clothes were prized more for the textiles from which they were made than for their design and aesthetic qualities as dress.

(Styles 1998: 383)

Before the Industrial Revolution and mass production, commodities (including textiles and clothing) were costly. Fibres were scarce and construction was time consuming, resulting in textiles and clothing being valued by their maker and owner (Rissanen 2013). Textiles had both economic and embodied value. The time spent spinning and dyeing fibre, and weaving the cloth, along with the skill and knowledge invested in the making process, contributed to their valued status (Rissanen & McQuillan 2016; McQuillan & Rissanen 2011; Fletcher 2008). Textiles were both precious and respected; there was a "horror of cutting into the body of the fabric." (Dalby 1993:151) and so cutting and waste were kept to a minimum.

With today's ease of manufacture we take textiles for granted and the wasting of cloth does not worry us.

(Burnham 1973: 3)

As both fashion and textiles became widely accessible, since the mechanisation of production (Section 5.4.1), the reverence and respect for textiles in the fashion industry has eroded.

Whilst textile waste is a consideration in industrial pattern cutting, this is based on economic and efficient use of fabric (it's yield) – minimising for cost rather than out of respect for the textile as cherished commodity or for sustainability purposes (McQuillan & Rissanen 2011). The linear nature of today's globalised supply chain, with its "division of labour" (Marx in Greenhalgh 1990: 92) has resulted in a disconnection between the individual (be that designer, pattern cutter, machinist or even the consumer) and the product:

> While the pattern cutter might have some sense of the amount of fabric waste that a single garment creates, she/he usually does not see the amount of waste created in the factory. The fashion designer is unlikely to even see the waste created by the sample garment.
>
> (Rissanen & McQuillan 2016: 43)

The devaluing of fashion is not isolated to the industry, it is also reflected in consumer behaviour – in their consumption, care and use of clothing. No longer is the consumer involved in or familiar with the processes, skills and knowledge required to manufacture the clothes that they wear. Instead "goods are emptied of the meaning of their production" (Sturken & Cartwright 2001: 200); through advertising and the media they have become fetishised objects – objects of desire, imbued with symbolic meaning (Ibid).

> Fashion has become a novelty and the commercialisation and marketing of fashion is leading to overconsumption and materialism – keeping our clothes is not in fashion any more.
>
> (Greenpeace 2016: 2)

The "embodied investments" (Rissanen & McQuillan 2016: 11) in garments (skill, resources and time) and "textile gestalt" (Townsend & Sadkowska 2018) have become invisible to the average consumer, leading them to consider fashion and textiles to be readily disposable.

5.4.3 The Changing Shape of Fashion: The Woven Silhouette

Traditional garments from across the world, including the toga, sari, poncho, huipil and shirt show a transition from simple to increasingly complex garment construction; loose-fitting geometric shapes are gradually replaced by closer fitting and structured (or tailored) silhouettes (Figure 5.5).

Tortora attributes this accumulative complexity of garment construction to the development of tools and technologies such as the loom, scissors and fastenings (buttons, pins, zips etc.) (Tortora 2015). Both Tortora and Burnham (1973) identify a correlation between construction, type of loom and the associated achievable width of the fabric. In her study of global dress 'Cut My Cote' Burnham states:

> Simple fabrics can be very similar in appearance regardless of period or area of origin, but man, with his infinitely varied cultures, has devised many shapes and sizes of looms with varying capacities […] If as in the ancient Mediterranean world, the loom was wide and capable of making a fair length of material, the resulting garments were wide and draped, whereas in the east the looms were narrow and the garments were seamed and comparatively tight.
>
> (1973: 2)

Burnham is credited as being the first to make this connection as well as for establishing "the relationship between fabric width, garment cut, and the resulting waste." (Rissanen & McQuillan 2016: 12). Building upon Burham's investigation, Timo Rissanen's PhD thesis 'Zero Waste Fashion Design: A Study at the Intersection of Cloth, Fashion Design and Pattern Cutting' (2013) extends the analysis of garment shapes. He considers the design and construction of past and present garments with a particular focus on waste minimisation and elimination. Rissanen makes a distinction between square-cut (geometric) and tailored (incorporating curves) garments and associates the evolution of garment silhouettes, from square-cut to more tailored construction, with increasing levels of cutting waste in fashion.

Conventional fashion has come to be dominated, at all levels, by tailored shapes and pattern cutting for the construction of garments using woven textiles (Rissanen 2013); resulting in an industry that generates an average of 15% - 20% cutting waste in garment production (Aakko & Niinimaki 2013; McQuillan 2010; Fletcher 2008; Abernathy et al. 1999)[5]. But traditional garments, such as the Japanese kimono, as well as single-piece and geometric construction, are not confined to the past. Designers

---

[5] This waste is estimated to have reached 60 billion square metres of cloth in 2015 (Rissanen & McQuillan 2016: 10).

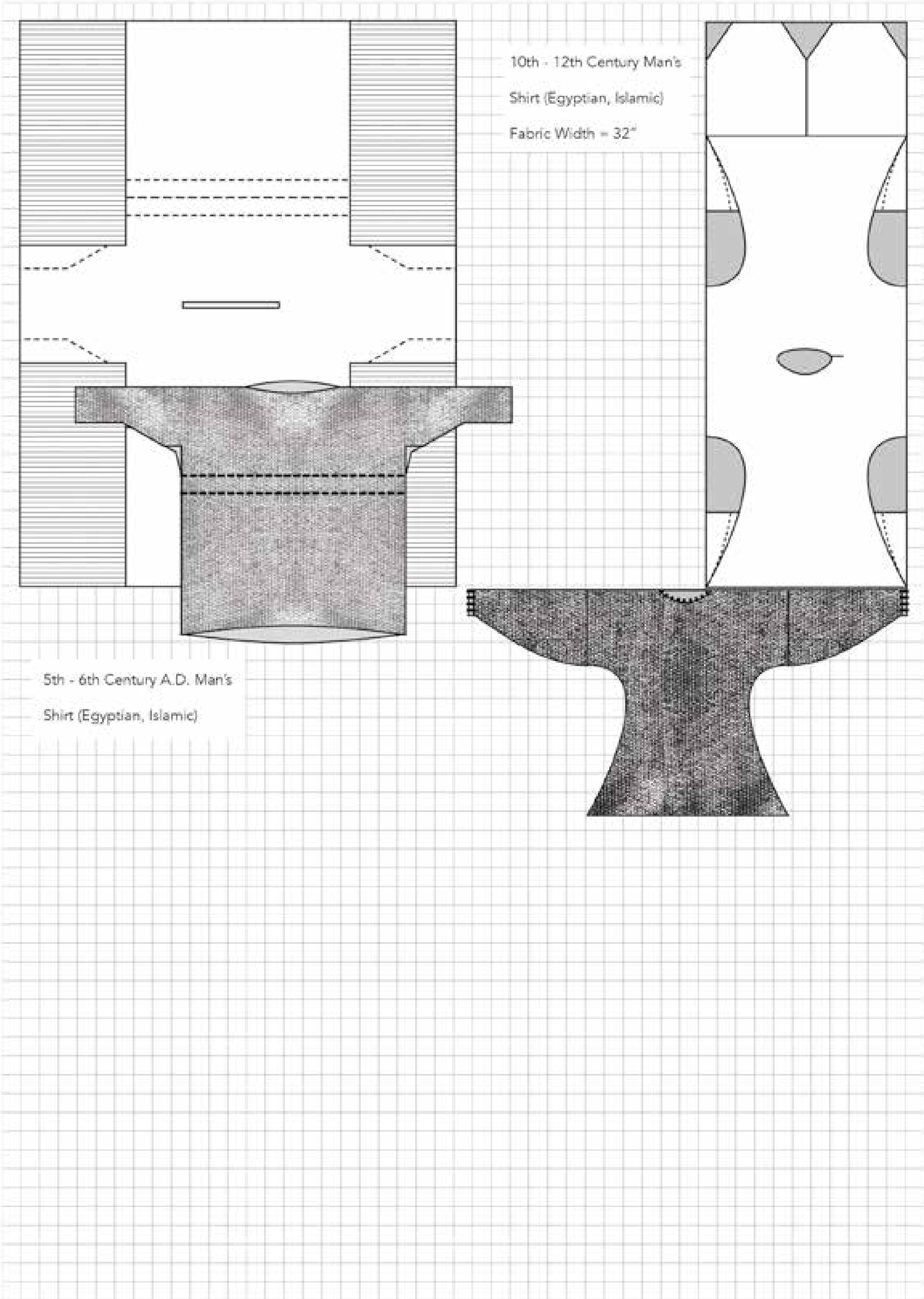
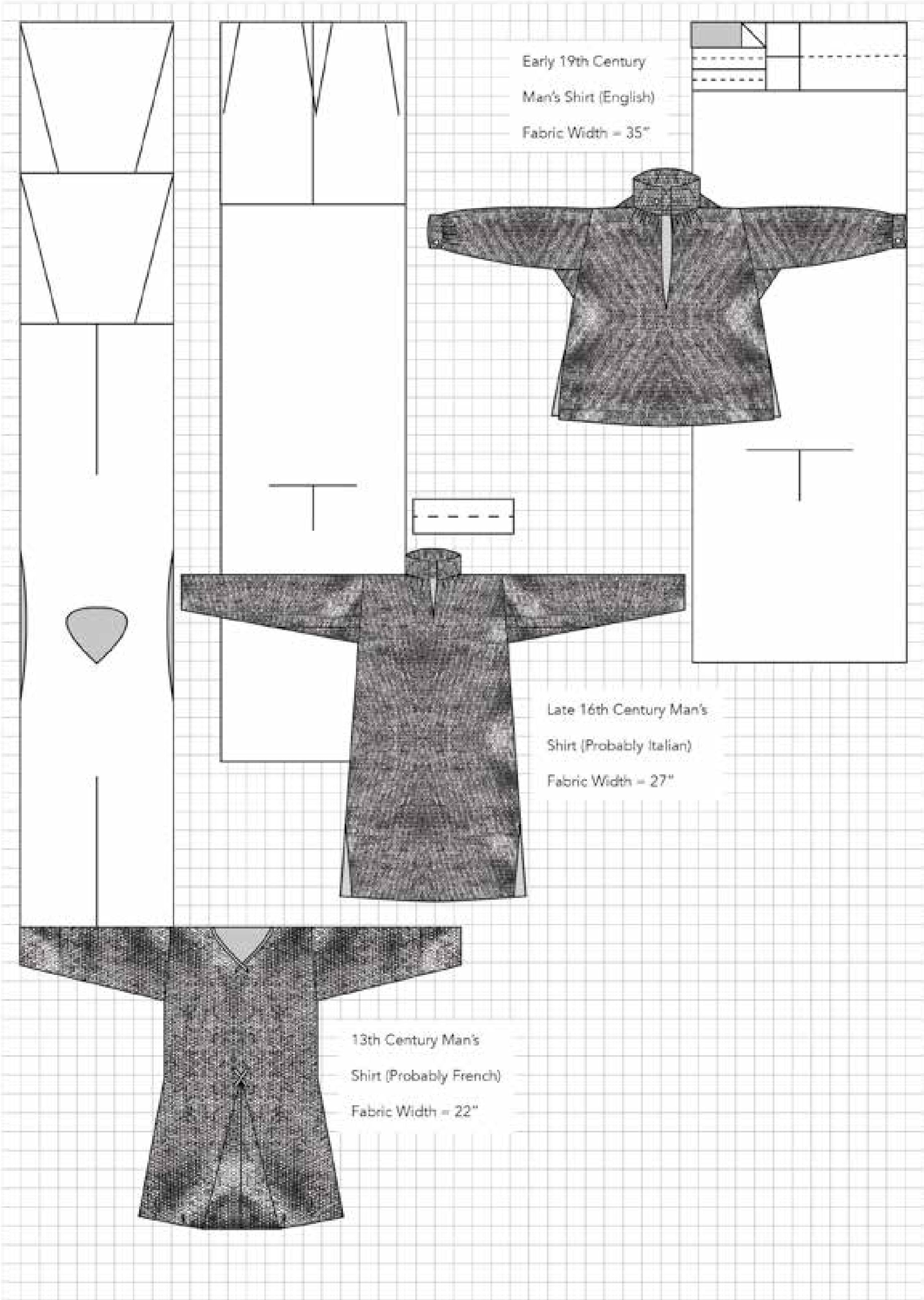


Figure 5.5: Evolution of Woven Garments (2018)
Illustration by Anna Piper Based on Illustrations in Burnham (1973)


Early 19th Century
Man's Shirt (English)
Fabric Width = 35"
Late 16th Century Man's
Shirt (Probably Italian)
Fabric Width = 27"
13th Century Man's
Shirt (Probably French)
Fabric Width = 22"

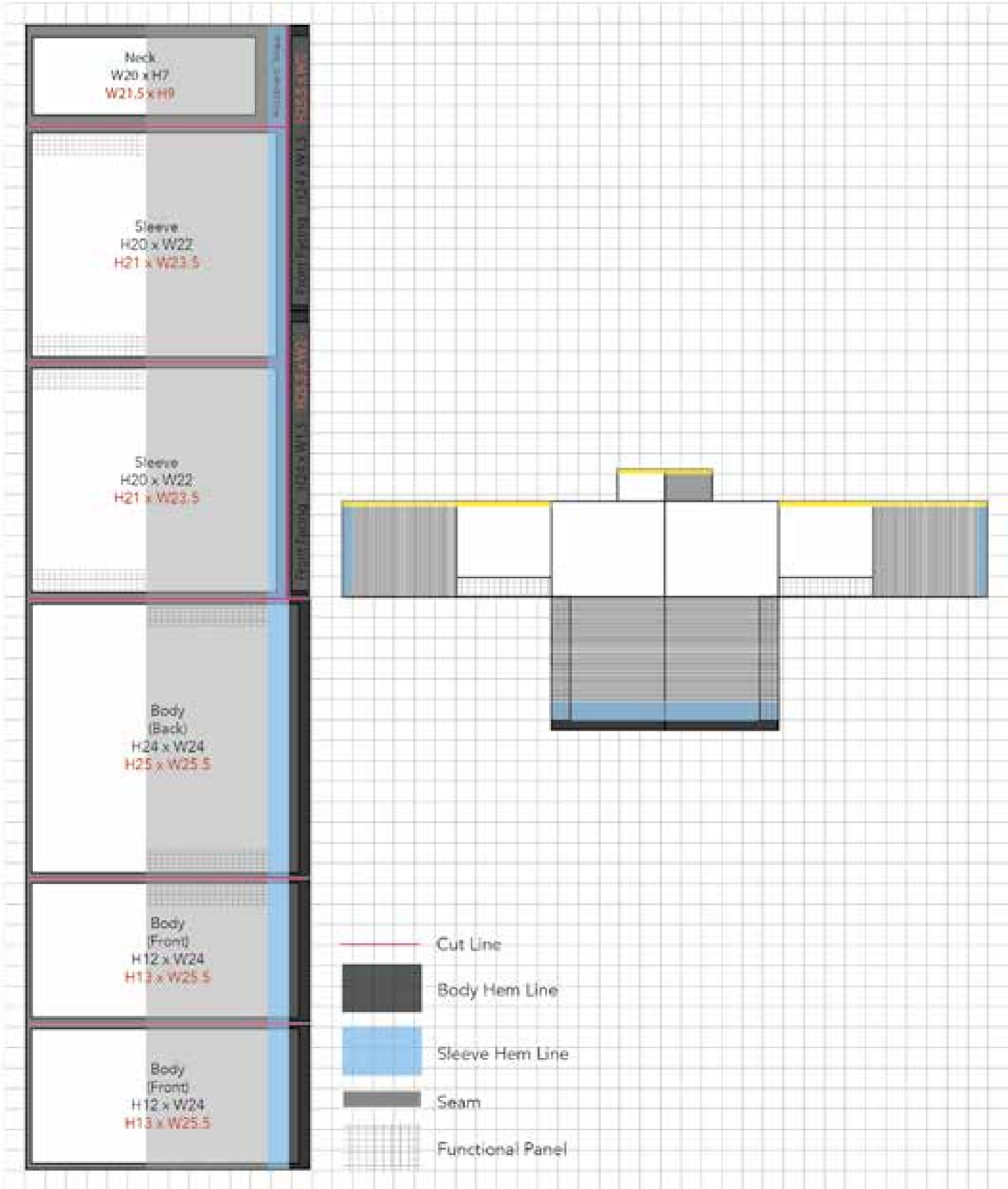


Figure 5.6: Jacket Lay-plan Using the Tessellation of Multiple Rectangular Blocks (2018)
Illustration by Anna Piper

including Issey Miyake, Rei Kawakubo and Celine continue to utilise traditional garments, construction and values as a platform for innovation. Furthermore, they are being utilised by designers, including Rissanen and McQuillan to combat and reduce pre-consumer cutting waste (Section 5.6) and to extend garment lifetimes (Section 5.8).

In this research these traditional approaches and construction values are employed and they inspire my approach to design both in relation to waste minimisation and garment functionality. For example, the Japanese kimono's geometric cut and proportions provide a blueprint for the design and construction of the jacket (Figure

5.6) and the coat, both of which use the tessellation of multiple rectangular pattern pieces to eliminate waste. The woven coat also draws from the Japanese tradition of repurposing waste to pad (or stuff) garments (Brown & McQuaid 2016). Whilst the hand woven t-shirt and Jacquard woven dress utilise single-piece and minimal construction methods to reduce the number of seams to facilitate comfort as well as reducing material consumption.

5.4.4 Continuing Consumption: Re-evaluating Textiles and Fashion

Despite the escalation in textile and fashion consumption and disposal, it is broadly accepted that encouraging society to stop consuming is not the answer (Black 2008; Chapman & Gant Eds. 2007). Changes in the way we design, produce, consume, use and dispose of products are necessary to achieve a more sustainable fashion system. To do this, "sustainable design needs to engage with human desire" (Chapman & Gant 2007: 7). A future of "eco-efficiency" (Ibid: 13) is required that demands a range of approaches to address the needs of the consumer, society, business and the environment. This involves responsible use of resources and products, effective design, responsible production and considered disposal.

As fashion and textile designers, we can learn lessons from historical construction techniques and principles – value our textiles and garments, by using them efficiently (Aspinall 2012). This can be assisted by developing and adopting iterative, integrated and holistic design methodologies to reconnect designers with resources and processes (Gwilt 2011).

5.5 The Issue of Fashion Waste

The rise in fast fashion (Section 5.4.1) brings with it a rise in textile and fashion waste. In 2004, combined textile and clothing waste in the UK reached 2.35 million tonnes, 74% of which went directly to landfill (Allwood et al. 2006: 16). It is broadly recognised that ever-increasing pressure and demand on natural resources (materials, energy, land etc.) is not environmentally sustainable (Greenpeace 2016; DEFRA 2013a; Fletcher & Grose 2012; Black 2008). Equally, it does not make economic sense. In 2011 alone UK businesses spent £885 million on waste management (DEFRA 2013a: 28). Although

Figure 5.7: Unusable Warp Threaded Through Heddles (2018)
Photograph by Anna Piper

high, this figure does not take into account the value of waste materials or the cost of time spent managing the waste (Ibid).

Waste is generated at both ends of the garment lifecycle - during fibre, textile and garment manufacture (pre-consumer waste) (Aakko & Niinimaki 2013; Brown 2013a) and when the consumer discards products (post-consumer waste) (Brown 2013b). In the fashion industry, pre-consumer waste includes cutting waste (fabric and threads), end of roles, sample headers, as well as damaged and flawed textiles and garments (Brown 2013a).

5.5.1 The Wastefulness of Weaving

The process of weaving is inherently wasteful, whilst ZWPC methods eliminate waste in the garment construction phase by using 100% of the fabric, waste is generated when the woven textile is constructed. The production of warp waste is inevitable as it is not possible to weave the entire length of the warp due to its attachment to the loom.

The warp is attached to the loom's back beam, the yarn is then threaded through the heddles - it is not possible to weave this section (Figure 5.7). Furthermore, to achieve the required tension for weaving, the warp must be attached to the loom's front and back beams. Tying the warp to the front beam generates lengths of waste yarn (Figure

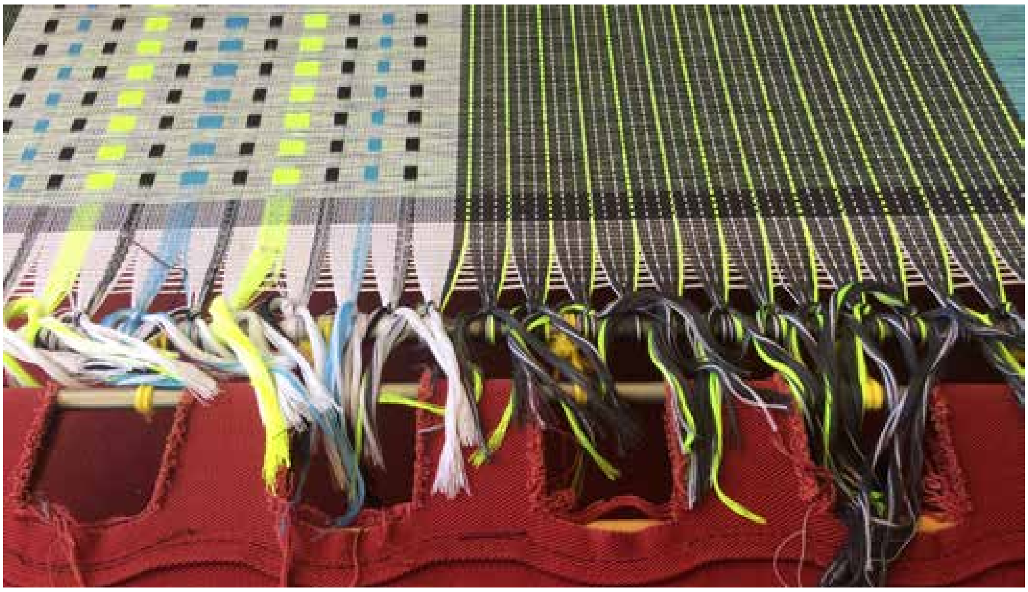


Figure 5.8: Warp Tied to the Front Beam (2018)
Photograph by Anna Piper

5.8). An allowance is made for this waste when calculating the required warp length for weaving. This allowance is dependent on the type and dimensions of the loom being used.

This clearly presents a challenge for any weaver seeking to eliminate production waste. Waste can be minimised by weaving as much of the warp as possible and by accurately calculating warp length requirements. However, my Postgraduate research (2013) revealed that the generation of usable lengths of waste to be integrated into subsequent designs was a more effective approach, as discussed in Section 5.3.1.

5.5.2 Waste Use and Elimination: The Waste Management Hierarchy

The Waste Management Hierarchy model (DEFRA 2013b) presents reduction and elimination as the most desirable method of addressing the issue of waste (Figure 5.9). Gertsakis and Lewis (2003) refer to elimination and reduction as a preventative measure, as once generated, resources (environmental, economic and human) are required to process and manage this waste. This applies if waste is upcycled, recycled or disposed of through landfill or incineration. The Waste Management Hierarchy ranks these options based on their environmental impact and desirability.

Figure 5.9: The Waste Management Hierarchy (2018)
Illustration by Anna Piper Based on Diagram by DEFRA (2013b)

By "designing out" (DEFRA 2013a: 9) and reducing pre-consumer waste, material and resource consumption can be minimised in the processing of fibre, fabric and fashion, resulting in environmental and economic gains (WRAP 2013). This is also reflected in 'Designing to Minimise Waste' (TED c.2016) being ranked as number one in TED's (Textile Environment Design)[6] 'The TEN' sustainable design strategies for textiles designers. However, even when pre-consumer waste is minimised or eliminated from the production process, products will inevitably come to the end of their usable life and become waste. This research addresses the notion of 'cradle to cradle' (Braungart & McDonough 2009) through interventions at the design stage to extend longevity and limit environmental impact at the end of a woven garment's lifecycle (Section 5.9).

[6] TED is the Textile Environment Design research group based at The University of the Arts, Chelsea. Established in 1996, the group consists of practising designers, academics and students undertaking research into sustainability and textile design, in collaboration with industry and leading researchers in the field of sustainable fashion and textile design. As part of this research they have produced a toolkit (or framework) for designers – 'The TEN' – to enhance understanding and to promote and support the integration of sustainable design strategies (TED c.2016; UAL c.2016).

5.6 Addressing the Issue of Pre-Consumer Fashion Waste: Pattern Cutting and Construction

Cutting waste in standard cut-and-sew garment construction averages 15% (Brown 2013a; Niinimaki & Armstrong 2013; McQuillan 2010; Fletcher 2008; Albanathy et al. 1999). This figure can be extrapolated across all stages of production (Brown 2013a). Designers have responded to this by drawing from traditional design principles and values, and by utilising technological developments to reduce material production and consumption and eliminate cutting waste in garment construction. This section details the approaches and developments in knitted and woven textiles and fashion design that reduce and eliminate the production of cutting waste.

5.6.1 Fully-fashioned and Seamless Knitting

> Knit waste can be avoided, either by knitting each garment piece to shape in what is called "fully fashioned" knitting, or with 3D or "whole-garment" machines that can create complete three-dimensional garments in a single no-sew process.
>
> (Brown & McQuaid 2016: 54)

In knitwear, fully-fashioned[7] and whole garment[8] production techniques are used industrially. Knitting's looped construction allows garment pieces and entire garments to be shaped and produced using circular, flatbed and 3D knitting processes (Section 4.6.3). Material production and consumption can be reduced by producing only the fabric required to construct the garment. Garment components are produced with integrated (or engineered) patterns that eliminate pattern matching and the associated cutting waste. Additionally, 3D seamless knitting is both mass-producible and a "mass customizable form for manufacturing." (Dion 2013: 106).

Unlike most other forms of garment design and construction fully-fashioned and seamless (whole garment) knitting requires the textile and the garment to be designed simultaneously. The use of CAD (required to programme seamless knitting machines, such as the Shima Seiki WHOLEGARMENT® knitting machine (Shima Seiki 2015)) adds

[7] Fully-fashioned knitwear: the production of shaped components that are assembled into garments.
[8] Whole garment construction (also known as integral and seamless knitting): single piece construction with integral shaping.

further complexity to the design process. Furthermore, it necessitates an integrated design approach through the assimilation of all process stages – a strategy that could lead to a more sustainable fashion system (Gwilt 2011; McQuillan 2010).

However, as Taylor and Townsend observe, "the full potential of seamless technology is still not being evidenced in high-fashion knitwear" (2014: 169). They attribute this to a "skills gap between knitwear designers and the technology" (Ibid: 157), that has initiated the development of standardised garment shape databases that support and facilitate the use of the software and hardware at a fundamental level.

5.6.2 Engineered Woven Pattern Production

> While Burnham (1973: 10) suggests that some basic garments were historically woven to shape, up until recently I knew of no contemporary mass-produced example in fashion (hand-woven examples are not unheard of).
>
> (Rissanen 2013: 153)

Fully-fashioned production in knitwear is commonplace in commercial fashion production. Whilst there are a number of designers producing bespoke hand woven garments constructed from shaped woven pattern pieces (see Manonik and friends of light – Section 4.3.1) and ongoing research projects exploring composite garment weaving as a means of minimising production waste (Lefferts 2015 - Section 4.3.3), commercial woven garment production is dominated by the production of fabric lengths and cut-and-sew construction.

One designer/technologist Siddaharta Upadhyaya, under the label name 'August', has developed a method of weaving engineered fully-fashioned pattern pieces with integrated pattern and embellishment (August 2011). The construction method is known as 'Direct Pattern on Loom Technology' (DPOL); it uses a Bonas Jacquard loom (Ukey, Kadole & Borikar 2013) to produce garment components with finished selvedges that are ready to stitch (Rissanen 2013). Upadahyaya cites business and design benefits that include the reduction of lead times, reduction of waste, exclusivity of design and seamless design (August 2011).

DPOL technology has been referred to as a zero waste form of production in a number of online sources (see for example Ghurye 2014 and Grady 2008). However, neither the 'August' promotional website nor the article by Ukey et al. (2013) featured in the journal 'Textile Science and Engineering' that evaluates the feasibility of DPOL make this claim. August suggests that the technology has the capacity to increase fabric utilisation "saving fabric > saving yarn" (August 2011). This reduction of waste is attributed to the ability to weave patterned garment components with engineered placement patterning (Ibid).

There is a lack of clarity in the information available about DPOL and the exact nature of the component construction. August claims that cutting waste is "ruled out" (Ibid), whilst Ukey et al. refer to panels woven on the loom that are "cut manually" (2013:1). Illustrated examples of pattern pieces using DPOL show components utilising the full width of the warp, but include sections of unwoven warp that would need to be cut from the final pattern piece that would generate yarn/warp wastage.

Most recently, McQuillan has embarked on a PhD investigating "a hybrid zero waste fashion practice" (McQuillan 2017a); applying "under-utilized" (McQuillan 2017b) digital Jacquard weaving to the production of zero waste garments. Early research outcomes include a t-shirt woven in multiple layers, cut and constructed off the loom, a fully-fashioned pocket and a composite set-in sleeve. The pieces thus far concentrate on the use of multi-layer weaving, cut and expanded to create three-dimensional (3D) forms. As in this research, McQuillan is working with a Jacquard loom with multiple harnesses, she is working creatively to utilise the narrow (40 cm) fabrics to constructed garments from a number of components.

5.6.3 Zero Waste Pattern Cutting

Zero Waste Pattern Cutting (ZWPC) is arguably the most widely referenced approach to eliminating cutting waste in fashion design and production. ZWPC's primary objective is to design garments that use 100% of a piece of fabric (Rissenen & McQuillan 2016; Townsend & Mills 2013). ZWPC does not, as a principal consideration, aim to reduce the material consumption of a garment. Although the fabric width is predetermined, the length is often determined during the design process (Rissanen 2013). In order to eliminate cutting waste, pattern pieces are tessellated, resulting in maximum (100%) fabric yield. Therefore, the selection of fabric width is intrinsic to the success of the design.

ZWPC disrupts the established linear process of fashion design by integrating the pattern and garment design processes (Rissanen & McQuillan 2016). It involves adopting a new way of thinking whereby the designer works iteratively between 2D pattern design and 3D toile construction throughout the design process (James, Roberts & Kuznia 2016) - an approach that requires intuition, the making of mistakes and risk taking (Lindqvist 2015; Roberts 2013; McQuillan 2011).

> Embrace risk in design as an access to new solutions; taking risks creates new possibilities. Designing within, and with, the fabric is integral to this kind of designing. In zero waste fashion design, fabric creates the space for inventive exploration.
>
> (Rissanen & McQuillan 2016: 84)

Both Townsend and Mills (2013), and Rissanen and McQuillan (2016) see ZWPC as a creative framework for the development of new methodologies, experimentation and innovation; increasing numbers of designers are taking on the challenge and a range of approaches and perspectives have ensued (Section 5.7).

5.6.4 Pattern Cutting and Construction: Informing Composite Pattern Weaving (CPW)

Elements of fully-fashioned and whole garment knitting, engineered woven pattern production and ZWPC's technical techniques, design processes and methodologies, all feature in CPW. The underlying principles of fabric efficiency and elimination of waste are at its heart. Established methods particularly in ZWPC and fully-fashioned knitting, as well as their limitations, provided a platform for experimentation, development and innovation. CPW and the Transitional Design Methodology (Section 3.3) offer new solutions and opportunities for zero waste design by extracting and combining aspects of each of the existing approaches, while addressing some of their challenges.

Despite the current limitations in design and application in seamless knitting in the fashion knitwear industry (Section 5.6.1), the shared level of complexity and similarities in combined textile/fashion construction provide a blueprint and a source of inspiration and technical know-how that inform the development of CPW. This includes the transfer of techniques to incorporate integral shaping into pattern pieces and components (Section 4.6.3), adaptation of shaping calculations (Section 7.5.1), as well as inspiration for engineered patterning for functional and aesthetic purposes.

In his thesis, Rissanen acknowledges the value of research into weaving technologies such as DPOL, stating:

> […] it is safe to assume that the fashion industry will continue to manufacture garments from lengths of fabric for the foreseeable future […] Technological solutions such as that offered by August are nevertheless welcomed.
>
> (Rissanen 2013: 33)

Rissanen's Jigsaw approach (Section 5.7.1 and Appendix 3) focused on tessellation and Miyake's A-POC (Section 4.3.3) pre-empt but do not state the possibility of integrating ZWPC techniques with engineered pattern production. CPW capitalises on the potential of engineered pattern production to reduce material production and consumption, and adopts ZWPC methods to eliminate cutting waste whilst conforming to the use of rectangular lengths of fabric. Significantly, CPW facilitates the inclusion of multiple fabric qualities within a single length of cloth, tailored to specific garment (functional and aesthetic) requirements, as well as engineered pattern placement for the purposes of pattern matching[9] (Section 5.8.3). It therefore innovatively balances both functional, aesthetic and sustainability demands within textile and garment design and production.

As with all sustainable fashion approaches, CPW does not present a total solution but it could be part of a sustainable design methodology that begins to address the issue of pre-consumer waste. There is also scope for it to encompass responsible material selection to facilitate end of life recycling (Section 5.9).

---

[9] Pattern matching can contribute to the production of pre-consumer fashion waste as cutting waste is generated through the positioning of garment components on the fabric to accommodate pattern matching rather than the purely concentrating on the most efficient use of the cloth.

5.7 Zero Waste Pattern Cutting: Principles and Practice

The aim of ZWPC is to eliminate cutting waste by utilising the entirety of a piece of cloth. Whilst this is the universal principle of the zero waste fashion design philosophy, designers also apply their own principles (or criteria) to their practice. This section looks at the range of strategies that have been developed by designers to produce zero waste garments.

5.7.1 Zero Waste Pattern Cutting: Process and Practice

Zero waste fashion design involves the simultaneous design of pattern and garment. The two processes become integrated and iterative (Rissanen & McQuillan 2016; James et al. 2016). Rather than starting with a sketch of a garment, zero waste design often begins with the pattern itself, with the intention of producing a particular type of garment (for example, a dress or a pair of trousers). The design evolves from a particular pattern piece or shape, depending on the approach (Figure 5.10). The established ZWPC methods (Tessellation, Jigsaw, Embedded Jigsaw and Multiple Cloth) and design approaches (Planned Chaos, Geo Cut, and Cut and Drape), along with an overview of their application in this study are outlined in Appendix 3.

There are a limited number of certainties inherent in the process – the width of the cloth, the "fixed area" (McQuillan 2011: 93) provided by the selected pattern piece/shape and the shared cut edges of pattern pieces. The process is therefore ingrained with degrees of uncertainty and risk regardless of the approach being employed. By starting with a pattern piece or shape, rather than a garment design to which the designer is working, the end result is unknown (Ibid). The designer must go through a process of working between 2D pattern drafting and 3D garment toileing – working both on paper and on the mannequin. Depending on the designer's experience, he/she may be able to envisage the way components will fit together and fit to the body (Ibid).

The process of ZWPC is therefore reliant upon the exploitation of certainty and risk (Pye 1968) as a creative tool, as well as being a cyclical process of incremental development and reflection, that requires the application of theory, skill and embodied knowledge.

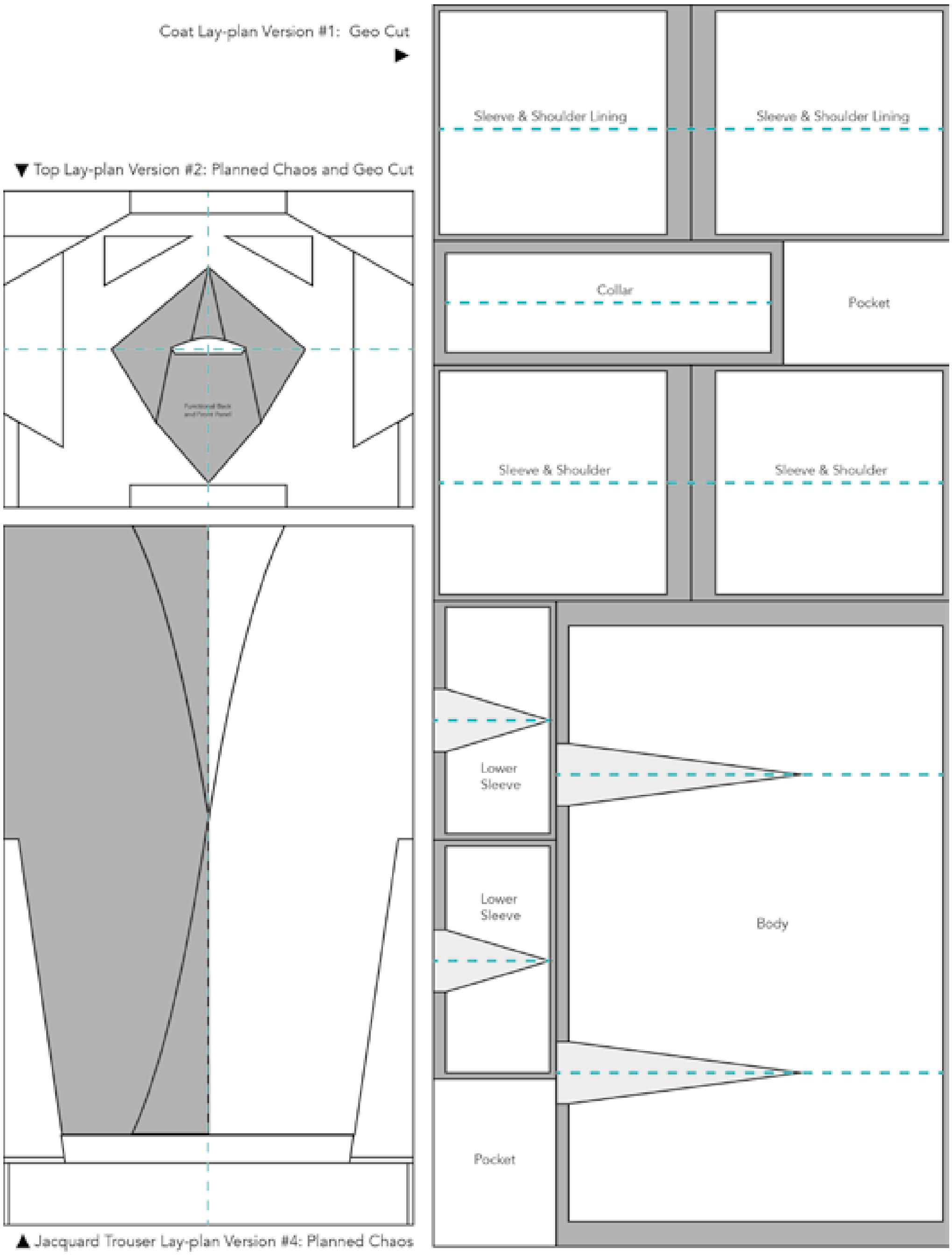


Figure 5.10: Zero Waste Pattern Cutting Apporaches Applied in CPW (2018)
Illustration by Anna Piper

5.7.2 Universal and Designer-specific Criteria

The physical certainties of zero waste fashion design are accompanied by a number of other criteria. Arguably, the only criteria of zero waste fashion design is that 100% of the fabric is utilised in the construction of a garment (or collection of garments). However, the zero waste design philosophy is embedded within the broader context of sustainable and responsible fashion design, and as such the design process and the elimination of cutting waste cannot be considered in isolation. The aesthetics and fit of a garment cannot be compromised in order to eliminate waste, as "A garment that isn't wanted is 100% waste." (McQuillan 2014). Rissanen and McQuillan identify a further three primary criteria depending on the context in which the garment is being designed and manufactured – cost, sustainability (relating to materials, durability and longevity) and manufacturability (2016: 89).

The three principles of (i) elimination of waste, (ii) aesthetics and (iii) fit, could therefore be considered as the Universal Criteria for zero waste fashion design, that accompany the physical certainties of fabric width, fixed area and shared cut edges of pattern pieces. However, some designers (myself included) apply further principles to their practice. These include designing for durability and longevity (Case Study 5.1), minimising cutting and seams (Case Study 5.2), and minimising material consumption by working with predetermined fabric lengths. These Designer-specific Criteria direct each particular design process, as well as being a platform for experimentation and innovation.

5.8 Addressing the Issue of Post-Consumer Fashion Waste: Extending Garment Lifetimes

An average household in the UK owns approximately £4,000 worth of clothes (WRAP 2013: 2) and the consumption of clothing has increased by 60% in the last 15 years (Greenpeace 2016: 2). Despite this increase in consumption, 30% of items in the average wardrobe have not been worn for over a year (WRAP 2013: 5).

> If clothes stayed in active use for nine months longer (extending the average garment life to around three years), this could save £5 billion a year from the costs of resources used in clothing supply, laundry and disposal.
>
> (Greenpeace 2016: 3)

Whilst the consumer has a considerable role to play in reducing fashion consumption, design can have a significant impact on garment lifetimes, consumer attitudes towards clothing, and the speed and means of garment disposal. Both aesthetic and technical factors in design can extend a garment's useable and desirable life (WRAP 2017; Oxborrow & Claxton 2016; Niinimaki & Armstrong 2013).

Case Study 5.1: ZWPC Designing for Durability and Longevity – Timo Rissanen

Dr Timo Rissanen is a fashion designer and Assistant Professor in Fashion Design and Sustainability based at Parsons, The New School for Design in New York. His research and practice focus on zero waste fashion design. In 2009 he began the 'Endurance Shirt' project. Taking inspiration from the evolution of men's shirts from the 18th Century onwards and from bespoke tailoring and haute couture practices, the project combines ZWPC and designing for longevity by creating garments that facilitate and encourage repair and alteration. Rissanen refers to repair and alteration as "transformative practices" (Rissanen 2011: 128). Through these transformative practices – engaging in repair – the user forms an emotional connection with the garment, a process that is initiated by the designer during the design process.

> *Many of the designers' thought processes are explicit in the garment, aiming to connect with the wearer. (Ibid: 132)*

Rissanen has explored a number of ways to facilitate and encourage repair, producing a number of shirts that incorporate additional (or excess) fabric in seam allowances, patches and panels to use to repair damage (rips and wear). Patches and hand-stitching create and embed a hand-crafted and visible repair aesthetic on which the user can build and add to the garment's 'story' through their own additions/repairs. This approach draws on the Japanese tradition of Sashiko quilting, a technique used to mend fishermen's coats, whereby the wear and repair of a garment becomes part of its appeal and emotional value (Ibid: 129).

> *Through the act of fixing, would be disposable products are meticulously repaired and upgraded. They are kept for vast periods of time, spanning generations, and become an integral part of that person's life. (Chapman 2013)*

Rissanen acknowledges that this approach may require greater material input in order to achieve longer-term use, which goes against the commercial fast fashion industry's objective of efficient pattern cutting to maximise profit (Grose in McQuillan & Rissanen 2011: 6). Instead the approach takes its cue from tailoring and haute couture; practices renowned for quality, craftsmanship and bespoke products, that involve the building of long-term relationships with clients and garments. Rissanen adopted this approach in 2015, when the 'Endurance Shirt' project began to redesign and personalise shirts to suit the user's body shape, size, tastes and needs (Rissanen & McQuillan 2016: 205).

Case Study 5.2: ZWPC Minimal Seam Construction – David Telfter

Specialising in zero waste and minimal seam design, David Telfer is a menswear designer working in the commercial fashion industry. He has worked alongside Dr Kate Goldworthy on the 'Laserline' project (2012) to develop ways of applying laser cutting technology in garment construction to cut, seam and embellish fabrics, and has collaborated with Tyvek to produce a zero waste "Painting Coverall" (2009) (Telfer 2017). Telfer has exhibited internationally, with his designs featured in exhibitions including 'Yield' (2010), an exhibition curated by Holly McQuillan and Timo Rissanen that explored ZWPC approaches, methods and applications.

Telfer believes in and applies the principles of "Local, Functional and Essential" (2017: Online) design. He adopts an approach to ZWPC and design that involves streamlining garment production. Through seam minimisation and reducing the complexity of garment construction he aims to enable faster garment production, which in turn has the potential to reduce energy consumption and the use of labour in manufacturing (McQuillan & Rissanen 2011: 24).

> *When implemented as a tool within a larger, effective system that intends overall positive effects on a wide range of issues – not simply economic ones – efficiency can actually be valuable. (Braungart & McDonough 2009: 65)*

Telfer has applied this sustainable design philosophy to a series of garments including his 'Zero Waste Duffle' (2010) (exhibited as part of 'Yield' (2010)). The men's coat is composed of a heavy-weight wool fabric and is constructed using only four seams. The garment uses a series of folds (at the shoulder, the sides, the hem and within in the hood) to form a geometric coat in a classic duffle style. It's simplicity, both in terms of cut and fabric quality, results in a contemporary functional aesthetic.

> *I liked the idea of starting with a square piece of fabric and finishing with a tailored, stylish garment without cutting the fabric into multiple pieces. (Telfer in McQuillan & Rissanen 2011: 24).*

A similar approach has been applied in Telfer's 'One Piece Pattern Cutting' series; a collection of garments, including two tailored men's shirts and a quilted coat, that explore the "design challenge" (Telfer 2017) of constructing clothing from a single piece of cloth. The pieces in this range feature complex curves within symmetrical patterns that assimilate the collar, facings, cuffs, sleeves, and front and back into a single piece of cloth. Cuts and seams are eliminated from the shoulders, with the sleeves and body folding around and connected at the seam-head. Despite their complex single-piece construction, the garments retain a conventional appearance; effectively balancing "aesthetics, fabric consumption, complexity of construction and fit" (McQuillan & Rissanen 2011: 24). Whilst Telfer concentrates on and specialises in minimal seam and single-piece construction to achieve manufacturing and material efficiency, his approach has the potential to facilitate end of life recycling through mono-material garment composition.

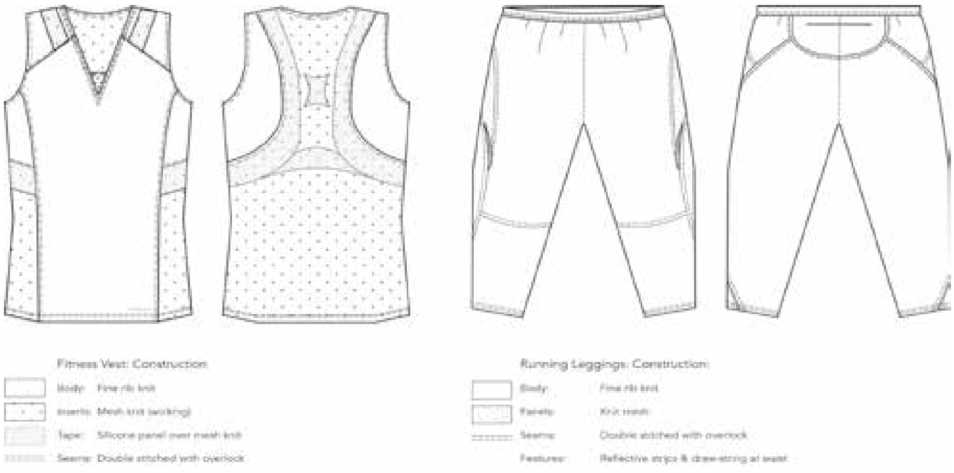


Figure 5.11: Multi-functional Panelling of Fabrics in Sportswear (2018)
Illustration by Anna Piper

> It is the combination of the right fabric with cut and construction techniques that makes the garment successful.
>
> (O'Mahony & Braddock 2002: 150)

WRAP's 2017 report 'Sustainable Clothing: A practical guide to enhancing durability and quality' specifies two types of durability – physical and emotional. The former relates to products resisting damage, the latter to garment desirability (Ibid). Both definitions recognise the impact of garment construction – material choice, style, cut, comfort and fit.

5.8.1 Delaying Disposal: Functional Durability – Wear and Tear

Relatively small practical additions in the design and construction of a garment can affect its capacity for resisting wear and tear. Increased durability can be achieved through the reinforcement of key areas that are prone to wear, for example the elbows of a jacket or the collar of a shirt. Including extra fabric within the garment, such as in the seams, also provides opportunities to adjust and repair garments.

Case Study 5.1 demonstrates these methods being assimilated with ZWPC techniques to respond to functional demands to enhance garment longevity. Timo Rissanen's research has explored ways of making garments both durable and adjustable to prolong their use, by using excess fabric to reinforce, provide structural support and

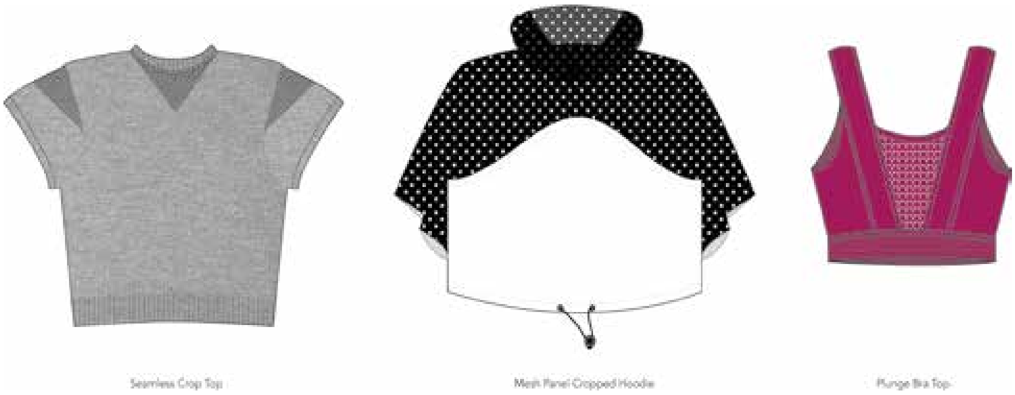


Figure 5.12: Panelling of Fabrics in High Street Activewear (2018)
Illustration by Anna Piper

increase seam allowances to facilitate adjustability (Rissanen 2011). He also highlights the importance of "high quality fabric" (Ibid: 136).

> Fabric quality depends on many variables, such as fibre type, blends, yarn structure, and fabric construction, as well as dyeing and finishing. Fabrics may carry the same description, such as 100% cotton, yet vary greatly in performance and durability.
>
> (WRAP 2017: 12)

Visible wear (such as pilling) or visible repair can negatively affect the consumer's perception of clothing, leading them to be discarded because they no longer 'look good', rather than no longer being physically fit for use (McLaren, Goworek, Cooper, Oxborrow & Hill 2016). Therefore, the compositional (choice of fibre(s)) and structural (type of weave) properties of the textile, and their positioning, are intrinsic to the physical durability and longevity of a garment. For example, polyester's abrasion resistance, strength, resilience, consistency, colour retention and cost make it a popular fashion fabric (WRAP 2017). However, these elements need to be balanced and prioritised with comfort, stylistic and economic (and in some cases sustainability) considerations; dictated by the type of garment (e.g. underwear or outerwear), intended use (e.g. fashion or performance) and market level (Watkins & Dunne 2015; McCann & Bryson Eds. 2009)[10].

5.8.2 Delaying Disposal: Functional Durability – Comfort and Fit

> Fabrics are the raw material, but are not passive components of garment construction.
>
> (Thomas 2009: 131)

The structure, composition and density of a woven fabric all contribute to its physical characteristics and suitability for application. The visual and tactile qualities inherent in a fibre and fabric can influence stretch (or stability), weight, handle and drape, whilst the technical (and often unseen) qualities can facilitate breathability, wicking, tear and abrasion resistance for example. Developments in fibre production and composition are increasingly able to enhance the functional performance of fabrics and garments (see for example Z Zegna's TECHMERINO™ SS2018 Collection). Even conventional fibres (such as wool and cotton) and common weave structures (e.g. plain weave and twills) can contribute significantly to the comfort and performance of clothing.

The integration, placement and application of fabrics with different constructions and characteristics within garments can provide advanced functionality and fit. This is most notable in specialist and performance garments that incorporate panelling of multi-functional fabrics, using both seamed and seamless construction (Figure 5.11). It is however increasingly evident in high street sports fashion and activewear (Figure 5.12), where it provides comfort, fit, and aesthetic impact (Walmsley-Johnson 2014; Salazar Ed. 2008).

The concept of "good fit" is defined by Watkins and Dunne as "the optimal relationship of the garment to the body for function, comfort and aesthetic needs." (2015: 71). In relation to garment cut, good fit is associated with freedom of movement

---

[10] There are many texts that provide in-depth analysis and discussion of fibre and fabric properties and application. It is beyond the scope of this research to further analyse in detail and test the physical durability characteristics of both fibres and weave structures. Instead, selection was informed by my exiting knowledge as a textile designer and a number of specialist sources including Johnson & Cohen 2010, McCann & Bryson Eds. 2009, Shishoo Ed. 2005 and Corbman 1983.

and sizing (Ibid). The sizing of mass produced garments is based on average bodily dimensions (for women – bust, waist and hip) to "accommodate as many body shapes as possible." (Townsend & Goulding 2011: 290). However, the variability in garment sizing and the use of out-dated sizing systems are seen to be barriers to consumers finding a satisfactory level of fit and comfort (Xia & Istook 2017). Lindqvist states that there is:

> […] a perception that a well-fitted garment is one that follows the shape of the wearer's body, creating a minimal amount of creases while still allowing the body to move about comfortably. This way of understanding fit is, however, as one-dimensional as identifying the quality of a garment solely through the concept of how long you can wear it before it falls apart.
>
> (Lindqvist 2013: 46)

Looser fitting and one-size garments along with the use of size adjustment features can optimise fit (Watkins & Dunne 2015) for different body shapes, and accommodate an individual's changes in body shape to encourage longer-term use (WRAP 2017).

5.8.3 Delaying Disposal: Aesthetic Desirability

Functional factors of fit, style and comfort are also critical factors in emotional and aesthetic durability and desirability, particularly for the female consumer (WRAP 2017).

> Other attributes, such as good functionality, emotional satisfaction, and aesthetical experiences (design, style, colour, and material choices), are also important, creating pleasurable use experiences at both physical and emotional levels.
>
> (Niinimaki & Armstrong 2013: 193)

Niinimaki and Armstrong's in-depth study into "person-product" attachment reveals that consumers consider beauty, colour and tactility to be important aesthetic attributes that can influence long-term use of clothing and consumer satisfaction (Ibid). Classic, simply styled and loose fitting garments along with core colour palettes (black, white, grey and navy) are encouraged in order to achieve continued desirability for longer-term use (WRAP 2017). Additionally, McCann, Morksky Hamk and Dong advocate

Case Study 5.3: Minimising Material Waste – COS X TEN COLLECTION

To celebrate their tenth anniversary in 2017, high street fashion brand COS released their COS X TEN Collection. The limited edition collection featured ten pieces, including women's, men's and childrenswear, all of which were designed to celebrate COS's "commitment to innovation and craftsmanship" (COS 2017a) whilst minimising material waste. The collection was accompanied by an online promotional video and individual garment descriptions to demonstrate/visualise how the items are constructed using pieces of fabric that "fit together like a puzzle" (Ibid.).

The collection cleverly fuses minimal waste pattern cutting with COS's signature minimalist, functional design aesthetic. Oversized geometric garments feature large practical patch-pockets, zips and tied fabric belts, with subtle applique patterns, tabs and plackets utilising excess (or waste) fabric. Modest plain coloured fabrics, clean curves and minimal detailing echo the utilitarian look of COS's standard/mainstream collection(s).

In describing the collection, COS refer to the garments as a collaboration between designers and pattern cutters; hinting at the complexity of the project in contrast to the deceptively simple garment shapes. By explicitly referencing both designers and pattern cutters, they affirm McQuillian and Rissanen's position that:

> *Pattern cutting in zero waste fashion design is a highly creative activity: it is fashion design […] In contrast to the dominant hierarchy of roles pattern cutting is integral to zero waste fashion design. (Rissanen & McQuillan 2016: 42)*

In doing so, COS demonstrate the commercial potential and viability of zero waste (or minimal waste) design methods in the retail fashion industry by addressing the "key challenge for zero waste fashion design" (2017b: 43) - the separation between fashion design and pattern cutting roles. They also, through their visuals, language and the garments themselves, expose the consumer to fashion design (and manufacturing) processes and introduce them to sustainability issues within fashion industry, as well as subtly engaging the consumer in the design and construction of their garments; an approach that has the potential to encourage consumers to emotionally and physically invest in their products.

> *[…] by cultivating an emotional and experiential connection between person and object, we can disrupt our dependency on consumption of new goods to construct meaning and our sense of self. (Fletcher 2012: 227)*

It is, however, important to acknowledge that the COS X TEN collection was relatively small-scale and short-term (a single collection, with a relatively limited garment range).

avoiding "styling that is driven by transient fashion with varying degrees of superficial embellishment" to create clothing that is "fit for purpose" (2009: 252).

Case Study 5.3, COS's 2017 'COS X TEN' Collection combines all of the elements outlined above with ZWPC methods (COS c.2017a). In doing so, they demonstrate the opportunities for ZWPC in commercial production, in a way that is consistent with their brand ethos and aesthetic of creating "modern, functional, considered design […] made to last beyond a season" (COS c.2017b). Their use of quality fabrics in plain colours, combined with simple cuts and oversized silhouettes creates a collection where functionality is central to the aesthetic, illustrating the aesthetic role of functionality in garment design and desirability/durability.

5.8.4 Delaying Disposal: Applying Composite Pattern Weaving for Durability

Aesthetic elements such as style, flattering design and the ability of a garment to make the wearer look and feel good are fundamental in both functional and emotional durability. It is clear that fibre, fabric and garment cut are all constituent in the durability of clothing, and their interconnectedness is intrinsic to a garment's capacity to facilitate comfort and fit[11]. Table 5.2 indicates the individual design features (aesthetic and functional), within each of the garments produced, applied to enhance garment durability and longevity.

By positioning weave structures strategically within a garment, differing levels of drape, stretch, insulation, breathability, abrasion resistance and stability (amongst other properties) can be achieved even when using a single fibre type. Table 5.3 provides an overview of the main durability and functional characteristics of the weave structures applied in the garments produced in this research[12]. If multiple yarn and fibre types are cleverly/strategically positioned greater diversity and functionality can be achieved.

---

[11] Journal Excerpts 5.1 and 5.2 show how fabric design, and yarn and weave structure selection were considered alongside the functionality durability and wear and tear when designing garment prototypes.

[12] The following sources were used to compile the weave structure characteristics outlined in Table 6.3: Briggs-Goode & Townsend Eds. 2011, Corbman 1983, McCann & Bryson Eds. 2009, Wilson 2010. The characteristics outlined are general characteristics that can be positively or negatively influenced by fabric composition and density.

Garment	Design Features	Garment	Design Features
Coat	• High density and durable weave structures to withstand wear and tear • Use of classic colours for cross-season appeal • Adjustable zip vents for freedom of movement and to accommodate different and changing body shapes	Dress	• Minimal seaming and stitching for comfort • Stretch panels to provide comfort and expandable fit • Simple classic silhouette to transcend seasons • Use of classic colours for cross-season appeal
Top	• High density and durable weave structures to withstand wear and tear • Positioning of stretch and expanding panels to aid freedom of movement • Positioning of breathable panels for thermo-regulation and comfort • Use of classic colours for cross-season appeal	T-shirt	• Positioning of breathable panels for thermo-regulation and comfort • Minimal seaming and stitching for comfort • Simple silhouette and relaxed fit to accommodate different and changing body shapes • Open and soft draping fabric for comfort
Jacket	• High density durable weave structure to withstand wear and tear • Variable yarn thickness to aid tear resistance • Positioning of breathable panels for thermos-regulation and comfort • Simple silhouette and relaxed fit to accommodate different and changing body shapes • Draw-strings to adjust fit and alter shape • Soft draping fabric for comfort	Trousers	• Positioning of stretch and expanding panels to shape and fit • Use of classic colour for cross-season appeal • Positioning of breathable panels for thermo-regulation and comfort • Draw-strings to adjust fit and alter shape

Table 5.2: Garment Design Features Contributing to Durability and Longevity

Weave Structure	Characteristics
Plain Weave	• Poor absorbency • Poor drape • Excellent abrasion resistance • Excellent fray resistance • Excellent snag resistance • Excellent stability
Hopsack (Basket)	• Poor fray resistance • Poor snag resistance • Good drape • Good moisture dispersion • Good wrinkle resistance • Good tear resistance
Huck Lace (Mock Leno)	• Poor fray resistance • Poor slippage resistance • Poor shrink resistance • Good breathability • Very good drape
Satin	• Poor fray resistance • Poor snag resistance • Good insulation • Good wind repellence • Excellent drape • Excellent tear resistance
Twill	• Good drape • Good wrinkle resistance • Good abrasion resistance • Good tear resistance • Very good dirt resistance • Very good durability
Waffle (Honeycomb)	• Poor abrasion resistance • Poor snag resistance • Very good insulation • Excellent bias stretch • Excellent absorbency • Excellent crease resistance

Table 5.3: Weave Structure Characteristics

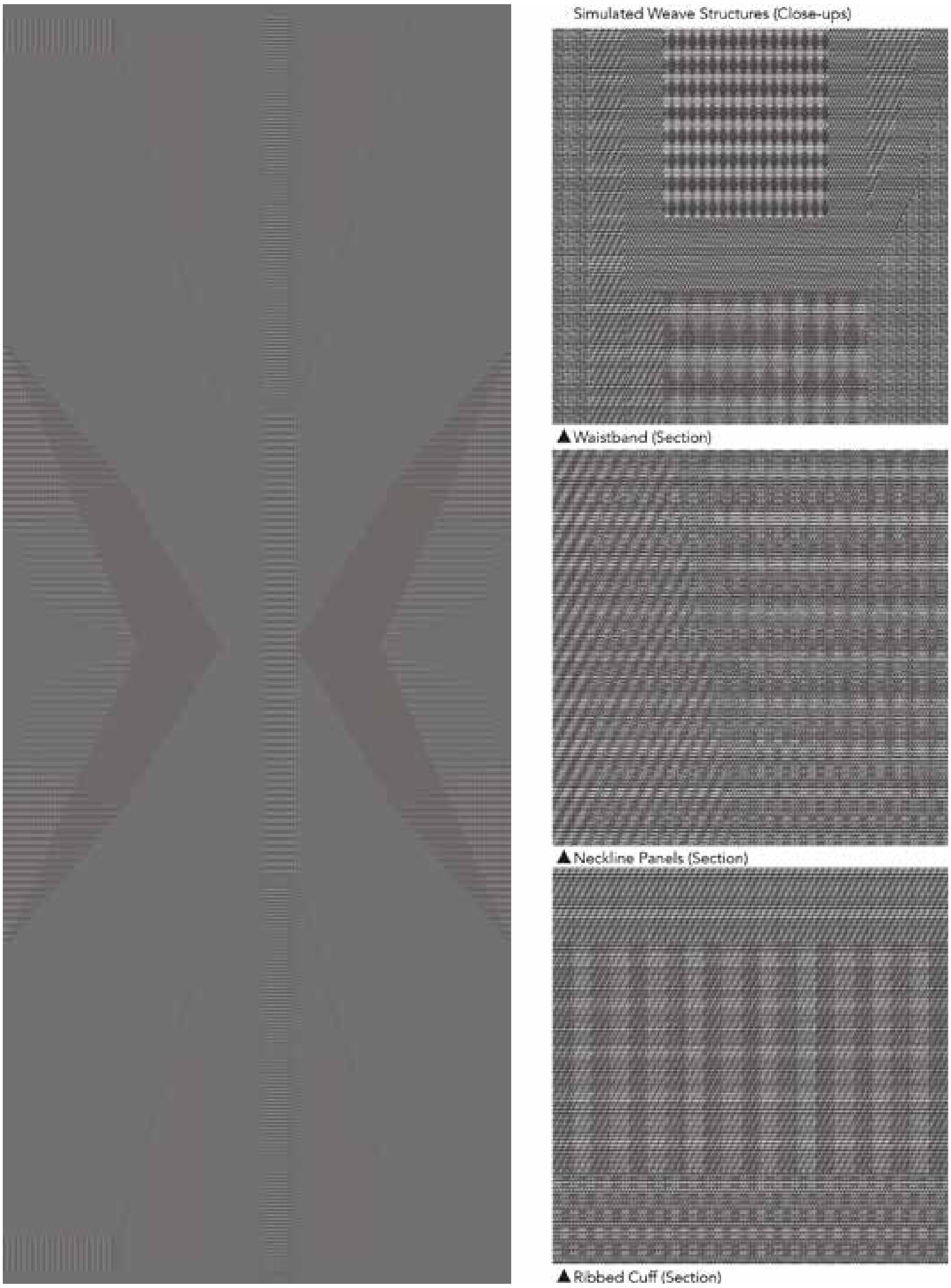


Figure 5.13: CPW Tops: Pointcarre Simulation (2018)
Illustration by Anna Piper

CPW techniques allow multiple fabric qualities to be integrated seamlessly within a single piece of cloth. Furthermore, they can be positioned within individual pattern pieces. A single pattern piece can contain a number of weave structures either to integrally shape the final garment or to respond to the needs of specific body parts. The ability to position and contour isolated sections/units of weave structures seamlessly can both reduce the number of pattern pieces required (thus reducing

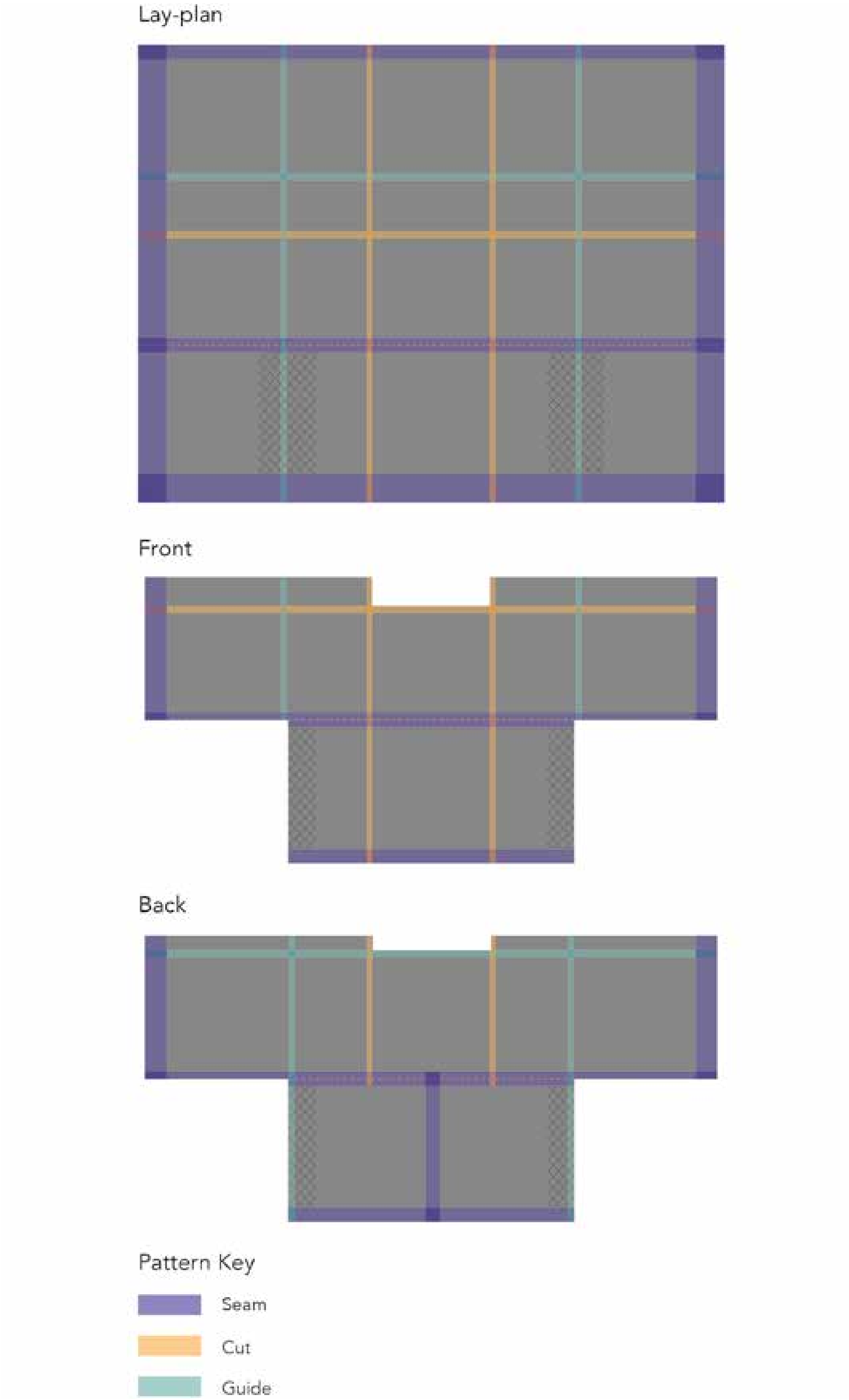


Figure 5.14: Colour Coding in Garments: T-shirt 'Coding' (2018)
Illustration by Anna Piper

material consumption by minimising/eliminating seam allowances) and allow complex engineered panels and patterns to be produced.

ZWPC techniques are limited in their ability to produce this level of variation, functionality and durability within fashion garments. Producing garments from a single piece of cloth gives uniformity and continuity of fabric characteristics throughout the garment, whilst seaming can restrict the subtlety and smoothness of shaped and contoured panelling. However, CPW's seamless panelling of fabric qualities can be combined with ZWPC methods to contribute to garment durability and functionality.

Figure 5.13 depicts a CPW prototype lay-plan using multiple weave structures to shape and fit the garment, to facilitate ease of movement through stretch and to assist in the regulation of body temperature using an open structure for ventilation. Utilitarian features – pockets and ties – provide added functionality and allow the wearer to adjust the fit. The combination of ZWPC and CPW techniques contribute to the styling of the garment and the aesthetic qualities of the textile.

The use of functionality as a design aesthetic inspires the design direction for garments produced in this study (Chapter 6). The relationship between the body, the material and the garment is fundamental, with garments being designed to perform both functionality and aesthetically in response to the physical and emotional needs of the wearer (Section 6.2.1). This informs the composition and design of the textiles and garments, using the CPW's simultaneous textile and fashion design, and integrated production to contribute aesthetic and functional longevity.

In addition to compositional attributes of the textiles, garment styling was also designed to contribute to garment longevity, through the use of simple, loose fitting but adjustable pieces to facilitate freedom of movement (Section 6.3.1) as well as accommodating changes in body shape and size. Core colours – black, white and grey (WRAP 2013) – were combined with vibrant accent colours to provide a contemporary look. However, colour application remained functional, with colour coding used to indicate cut and fold lines as well as seams and hems (Figure 5.14) (Section 6.4.4).

5.9 Addressing the Issue of Post-Consumer Fashion Waste: End of Life Disposal

Even if a garment is produced using ZWPC or CPW methods to eliminate pre-consumer waste, and strategies are put in place to enhance its longevity, there will come a time when a piece comes to the end of its useful life and becomes waste.

> […] ultimately, we need to both close the loop – by recycling the fibres into virgin material to make new clothes – and to slow down the rate that we consume by focussing on the clothes that are needed and re-thinking the systems used to supply them, taking in all stages from their design to their re-use or recycling […] Better quality clothes need to be designed, which are durable, fit the customer's needs, are repairable, re-usable and at the end of their lives, completely recyclable - and which customers will cherish for many years.
>
> (Greenpeace 2016: 7)

An inhibiting, and in most cases prohibiting, factor when it comes to garment, fabric or fibre recycling is the mixing of virgin fibres. Although chemical separation techniques for composite fibres and fabrics have been and continue to be developed, their availability, practicality and sustainability limit their use (Greenpeace 2016; Industrial Fabrics Association International 2015).

Weaving provides infinite possibilities for fabric composition, with the ability to combine multiple fibre types both in the warp and the weft to suit the particular application but also to meet other design criteria (aesthetic and functional). This criterion is determined by the specific project as well as the designer's design philosophy and style.

Material choices in this research were based on a number of factors - dictated by technical construction methods, garment functionality (technical, aesthetic and sustainable), and my personal sustainable design principles (Section 5.3). Material selection principles, listed below, are based on the ability to recycle garments at the end of their useable life to eliminate (or avoid) the need to dispose of them in landfill.

Further details of the sustainability factors that influenced material selection in this study can be found in Appendix 4.

- To use only mono-fibre yarns (natural or synthetic) in fabric composition
- To produce single-fibre fabrics and garments
- To utilise warp waste in the construction of subsequent designs

5.10 Sustainability: Chapter Conclusion

This chapter has outlined the sustainability framework and criteria applied in the in the development of CPW, as well as considering the influential debates and established methodologies that inform and contextualise this research. The key principles of fabric efficiency, eliminating cutting waste, responsible material selection, and the production of functionally durable and aesthetically desirable garments, have shaped the study's design and production processes and final garment outcomes. Each garment applies these criteria in different ways; responding to the type of garment being developed, adapting to the mode of production, and capitalising on the successes and set-backs (opportunities and limitations) of preceding (and parallel) experiences and outcomes. This has culminated in a series of garments that have been designed in 'conversation' with one another, whereby existing lay-plans provide a model for subsequent designs, fabric/garment construction and design features are refined, and waste from one garment is integrated into the next.

5.11 References

AAKKO, M. & NIINIMAKI, K. (2013). 'Experimenting with Zero-waste Fashion Design'. In: NIINAMKI, K. (Ed). (2013). *Sustainable Fashion: New Approaches*. Helsinki: Aalto University. pp. 68-79. Available at: https://shop.aalto.fi/media/attachments/1ee80/SustainableFashion.pdf Accessed: 12 July 2018.

ABERNATHY, F, H. DUNLOP, J, T. HAMMOND, J, H. & WEIL, F. (1999). A *Stitch in Time: Lean Retailing and the Transformation of Manufacturing - Lessons From the Apparel and Textile Industries*. Oxford: Oxford University Press.

ALDRICH, W. (2008). *Metric Pattern Cutting for Women's Wear*. (5th Edition). Oxford: John Wiley & Sons.

ASPINALL, M. (2012). "Design That Looks at Models from History and Nature'. *Textile Tool Box*. Available at: http://www.textiletoolbox.com/research-writing/design-look-models-history-and-nature/. Accessed: 09 November 2018.

AUGUST. (2011). 'August Fashion'. *August Fashion*. Available at: http://august.synthasite.com/. Accessed: 03 January 2014.

BHARDWAJ, V. & FAIRHURST, A. (2010). 'Fast Fashion: Response to Changes in the Fashion Industry'. *The International Review of Retail, Distribution and Consumer Research*. 20(1). pp. 165-173. DOI: 10.1080/09593960903498300.

BLACK, S. (2008). Eco-Chic: The Fashion Paradox. London: Black Dog.

BRAUNGART, M. & McDONOUGH, W. (2009). *Cradle to Cradle: Remaking the Way We Make Things*. London: Vintage.

BRIGGS-GOODE, A. & TOWNSEND, K. (Eds.). (2011). *Textile Design: Principles, Advances and Applications*. Oxford: Woodhead Publishing.

BROWN, S. & MCQUAID, M. (2016). *Scraps: Fashion, Textiles, and Creative Reuse*. New York: Cooper Hewitt.

BROWN, S. (2013a). 'Design for Cyclability: Pre-Consumer Waste'. *Textile Toolbox.* Available at: http://www.textiletoolbox.com/posts/pre-consumer-waste/. Accessed: 04 December 2014.

BROWN, S. (2013b). 'Design for Cyclability: Post Consumer Waste'. *Textile Toolbox* Available at: http://www.textiletoolbox.com/posts/post-consumer-waste/. Accessed: 04 December 2014.

BURNHAM, D, K. (1973). *Cut My Cote*. Toronto: Royal Ontario Museum.

CHAPMAN, J. (2013). 'Repair'. *Textile Toolbox*. Available at: http://www.textiletoolbox.com/research-writing/repair/. Accessed: 09 November 2018.

CHAPMAN, J. & GANT, N. (Eds). (2007). *Designers, Visionaries and Other Stories: A Collection of Sustainable Design Essays*. London: Earthscan.

CORBMAN, B, P. (1983). T*extiles: Fiber to Fabric*. (6th Edition). London: McGraw-Hill.

COS. (c.2017a). 'Creating Ten Years of COS'. *COS*. Available at: https://www.cosstores.com/gb/Studio/Projects/10. Accessed: 28 August 2017.

COS. (c.2017b). 'About COS'. *COS*. Available at: https://www.cosstores.com/gb/. Accessed: 28 August 2017.

DALBY. L. (1993). *Kimono: Fashioning Culture*. New Haven: Yale UP.

DEFRA UK. (2013a). 'Prevention Is Better than Cure: The Role of Waste Prevention in Moving to a More Resource Efficient Economy'. *The Waste Prevention Team DEFRA*. Available at: https://www.gov.uk/government/policies/reducing- and-managing-waste. Accessed: 03 January 2014.

DEFRA UK. (2013b). 'Waste Prevention Programme for England: Overview of Evidence – A Rationale for Waste Prevention in England'. *The Waste Prevention Team DEFRA*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/264909/wpp-evidence-overview.pdf. Accessed: 03 January 2014.

DION, G. (2013). 'Haute Tech Couture: Digital Fabrication of Wearable Technology' in *Proceedings of the First International Conference on Digital Fashion*. pp. 106–12. London: University of the Arts. 16-17 May 2013.

DOSA. (c.2017). 'Life of Jamandi Project'. *Dosa Inc*. Available at: https://dosainc.com/specialprojects/life-of-jamdani. Accessed: 12 July 2018.

FLETCHER, K. (2012). 'Durability, Fashion, Sustainability: The Processes and Practices of Use'. *Fashion Practice*. (4(2). pp 221-238.

FLETCHER, K. (2008). *Sustainable Fashion and Textiles: Design Journeys*. London: Earthscan.

FLETCHER, K. & GROSE, L. (2012). *Fashion and Sustainability: Design for Change*. London: Laurence King.

GERTSAKIS, J. & LEWIS, H. (2003). 'Sustainability and the Waste Management Hierarchy: A Discussion Paper on the Waste Management Hierarchy and Its Relationship to Sustainability'. Available at: http://scholar.googleusercontent.com/scholar?q=cache:bL3QfoXj6L8J:scholar.google.com/+Sustainability+and+the+Wast. Accessed: 03 January 2014.

GHURYE, S. (2014). 'Cutting Edge Trends in the Fashion Design Industry – Zero waste Fashion'. *Fuel4Fashion*. Available at: https://fuel4fashion.wordpress.com/tag/siddhartha-upadhyayas-dpol-direct-pattern-on-loom/. Accessed: 06 July 2017.

GLOBAL FASHION CONFERENCE. 2018. ' What's Going On? A Discourse on Fashion, Design and Sustainability Programme'. *Global Fashion Conference*. Available at: http://gfc-conference.eu/wp-content/uploads/2018/10/GF2018_PROGRAMME-FINAL.pdf. Available at: http://gfc-conference.eu/wp-content/uploads/2018/10/GF2018_PROGRAMME-FINAL.pdf. Accessed: 08 November 2018.

GOLDSWORTHY, K. & TELFER, D. (2012). 'Seamsdress'. *Textile Toolbox*. Available at: http://www.textiletoolbox.com/media/uploads/project-downloads/seamsdress.pdf. Accessed: 09 November 2018.

GRADY, E. (2008). 'High Tech Meets Low Waste in New Computer Generated Eco Fashion'. *Treehugger*. Available at: https://www.treehugger.com/style/high-tech-meets-low-waste-in-new-computer-generated-eco-fashion.html. Accessed: 06 July 2017.

GREENPEACE. (2016). 'Timeout for Fast Fashion'. *Greenpeace: Hamburg*. Available at: http://www.greenpeace.org/international/Global/international/briefings/toxics/2016/Fact-Sheet-Timeout-for-fast-fashion.pdf. Accessed: 06 July 2017.

GREENHALGH, P. (1990). 'Introduction to Modernism in Design'. In: LEES-MAFFEI, G. & HOUZE, R. (2010). The Design History Reader. Oxford: Berg. pp. 91-97.

GWILT, A. (2011). 'Make - Producing Sustainable Fashion'. In: GWILT, A. & RISSANEN, T. (Eds.). (2011). *Shaping Sustainable Textiles: Changing the Way we Make and Use Clothes*. London: Earthscan. pp. 59-73.

INDUSTRIAL FABRICS ASSOCIATION INTERNATIONAL. (2015). 'Progress in Separating, Recycling Cotton and Polyester Blends'. I*ndustrial Fabrics Association International*. Available at: https://www.ifai.com/2015/07/15/progress-in-separating-recycling-cotton-and-polyester-blends/. Accessed: 25 September 2017.

JAMES, A, M. ROBERTS, B, M. & KUZNIA, A. (2016). 'Transforming the Sequential Process of Fashion production: Where zero-waste pattern cutting takes the lead in creative design'. *International Journal of Fashion Design, Technology and Education.* 9(2). pp. 142 -152. DOI: 10.1080/17543266.2016.1167253.

JOHNSON, I. & COHEN, A, C. (2010). *Pizzuto's Fabric Science*. (9th Edition). United States: Fairchild Books.

LINDQVIST, R. (2015). 'Kinetic Garment Construction: Remarks on the Foundations of Pattern Cutting'. (PhD Thesis). Boras: The Swedish School of Textiles, University of Boras.

LINDQVIST, R. (2013) 'On the Logic of Pattern Cutting: Foundational Cuts and Approximations of the Body'. (Licentiate Thesis) Boras: The Swedish School of Textiles, University of Boras. Available at: http://bada.hb.se/handle/2320/11957. Accessed: 09 January 2015.

MCCANN, J. & BRYSON, D (Eds.). 2009. *Smart Clothes and Wearable Technology*. Cambridge: Woodhead Publishing in Textiles.

MCCANN, J. MORKSKY HAMK, S. & DONG, X. (2009). 'Garment Construction: Cutting and Placing of Materials'. In: MCCANN, J. & BRYSON, D. (Eds.). (2009). *Smart Clothes and Wearable Technology*. Cambridge: Woodhead Publishing in Textiles. pp.235–261.

MCLAREN, A. GOWOREK, H. COOPER, T. OXBORROW, L. & HILL, H. (2016). 'The Effects of Consumer Attitudes on Design for Product Longevity: The Case of the Fashion Industry'. In: *Design Research Society 50th Anniversary Conference Proceedings*. pp.3831-3846. Brighton: University of Brighton. 27-30 June 2016.

MCQUILLAN, H. (2017a). ' PhD: Hybrid Zero Waste Fashion Practice. *Holly McQuillan*. Available at: https://hollymcquillan.com/portfolio/hybrid-zero-waste-practice/. Accessed: 27-Sep-2018.

MCQUILLAN, H. (2017b). '2017 GWNZ Fellowship: Mid-Term Report'. *Graduate Women New Zealand*. Available at: http://www.gwnz.org.nz/wp-content/uploads/2017/05/McQuillan-Holly-mid-term-report-17.pdf. Accessed: 27-Sep-2018.

MCQUILLAN, H. (2014). *Zero Waste Fashion and Textile Design Seminar.* London: UAL Chelsea College of Art. 28 March 2014.

MCQUILLAN, H. (2011). 'Zero Waste Design Practice: Strategies and Risk Taking for Garment Design'. In: GWILT, A. & RISSANEN, T. (Eds.). (2011). *Shaping Sustainable Textiles: Changing the Way we Make and Use Clothes.* London: Earthscan. pp. 83-97.

MCQUILLAN, H. (2010). 'Zero-Waste Pattern Cutting Process'. *Holly McQuillan*. Available at: http://hollymcquillan.com/download/. Accessed: 04 December 2013.

MCQUILLAN, H. & RISSANEN, T. (2011). 'Yield: Making Fashion Without Making Waste' (Exhibition Catalogue). *Yield*. Available at: http://yieldexhibition.com/. Accessed: 04 December 2013.

NIINIMAKI, K. & ARMSTRONG, C. (2013). 'From Pleasure in Use to Preservation of Meaningful Memories: A Closer Look at the Sustainability of Clothing via Longevity and Attachment'. *International Journal of Fashion Design, Technology and Education*. 6(3). pp. 190-199. DOI: 10.1080/17543266.2013.825737.

O'MAHONY, M. & BHRADDOCK, S, E. (2002). *SportsTech: Revolutionary Fabrics, Fashion and Design*. London: Thames & Hudson.

OXBORROW, L. & CLAXTON, S. (2016). 'Extending Clothing Lifetimes: An Exploration of Design and Supply Chain Challenges'. In: *Design Research Society 50th Anniversary Conference Proceedings*. pp. 3815-3830. Brighton: University of Brighton. 27-30 June 2016.

PYE, D. (1968). *The Nature & Art of Workmanship*. Cambridge: Cambridge University Press.

RISSANEN, T. & MCQUILLAN, H. (2016). *Zero Waste Fashion Design*. London: Bloomsbury.

RISSANEN, T. (2013). 'Zero-Waste Fashion Design: A Study at the Intersection of Cloth, Fashion Design and Pattern Cutting'. (PhD Thesis). Sidney: University of Technology Sidney.

RISSANEN, T. (2011). ' Designing Endurance' Fashion' in GWILT, A. & RISSANEN, T. (Eds.). (2011). *Shaping Sustainable Textiles: Changing the Way we Make and Use Clothes*. London: Earthscan. pp. 127-138.

ROBERTS, J. (2013). 'Free Cutting'. *The Cutting Class*. Available: https://www.thecuttingclass.com/subtraction-pattern-cutting-with-julian-roberts/. Accessed: 08 November 2018.

SALAZAR, L. (Ed.). (2008). *Fashion V Sport*. London: V&A Publishing.

SHIMA SEIKI. (2015).'WHOLEGARMENT'. *Shima Seiki*. Available at: http://www.shimaseiki.com/wholegarment/. Accessed: 03 February 2016.

SHISHOO, R. (Ed.). (2005). *Textiles in Sport*. Cambridge: Woodhead Publishing in Textiles.

STYLES, J. (1998). 'Dress in History: Reflections on a Contested Terrain'. *Fashion Theory.* 4(2). pp. 383-390.

STURKEN, M. & CARTWRIGHT, L. (2001). *Practices of Looking: An Introduction to Visual Culture*. London: Oxford University Press.

TAYLOR, J. & TOWNSEND, K. (2014). 'Reprogramming the Hand: Bridging the Craft Skills Gap in 3D/digital Fashion Knitwear Design'. *Craft Research*. 5(2). pp. 155–174.

TED. (c.2016). 'The TEN'. *Textile Environment Design*. Available at: http://www.tedresearch.net/teds-ten/. Accessed: 26 September 2017.

THOMAS, L. (2009). 'Woven Structures and Their Impact in the Function and Performance of Smart Clothing'. In: MCCANN, J. & BRYSON, D. (Eds.). (2009) *Smart Clothes and Wearable Technology*. Cambridge: Woodhead Publishing in Textiles. pp.131–155.

TORTORA, P, G. (2015). *Dress, Fashion and Technology: From Prehistory to the Present*. London: Bloomsbury.

TOWNSEND, K. & SADKOWSKA, A. (2018). 'Textiles as Material Gestalt: Cloth as a Catalyst in the Co-designing Process'. *Journal of Textile Design and Research Practice*. 5(2). pp. 208-231.

TOWNSEND, K. & MILLS, F. (2013). 'Mastering Zero: How the Pursuit of Less Waste Leads to More Creative Pattern Cutting'. *International Journal of Fashion Design, Technology and Education*. 6(2). pp. 104–111.

TWIGGER HOLROYD, A. (c.2017). 'Keep and Share'. *Amy Twigger Holroyd*. Available at: https://amytwiggerholroyd.com/Keep-Share. Accessed: 12 July 2018.

UAL. (c.2016). 'Textile Environment Design'. *The University of the Arts London*. Available at: http://www.arts.ac.uk/research/researching-at-ual/research-infrastructure/research-groups-networks-and-collaborations/textiles-environment-design/. Accessed: 26 September 2017.

UKEY, P, P. KADOLE, V & BORIKAR, S. (2013). '"Direct Pattern on Loom" – An Innovative Method of Garment Construction'. *Textile Science & Engineering*. 3(2). p. 131.

WALMSLEY-JOHNSON, H. (2014). 'Sports Luxe: Does It Work for Older Women?'. *The Guardian*. Available at: http://www.theguardian.com/fashion/2014/oct/29/sports-luxe-does-it-work-for-older-women. Accessed: 15 May 2015.

WATKINS, S, M. & DUNNE, L, E. (2015). *Functional Clothing Design: From Sportswear to Spacesuits*. London: Bloomsbury.

WILSON, E. (2003). *Adorned in Dreams: Fashion and Modernity*. London: IB Tauris & Co Ltd.

WILSON, J. (2010). *Classic and Modern Fabrics: The Complete Illustrated Source Book*. London: Thames & Hudson.

WRAP. (2017). 'Sustainable Clothing: A Practical Guide to Enhancing Clothing Durability and Quality'. *WRAP*. Available at: http://www.wrap.org.uk/sites/files/wrap/Sustainable%20Clothing%20Guide%202017.pdf. Accessed: 20 September 2017.

WRAP. (2013). 'Valuing Our Clothing: The True Cost of How We Design, Use and Dispose of Clothing in the UK'. *WRAP*. Available at: http://www.wrap.org.uk/content/valuing-our-clothes. Accessed: 11 May 2015.

XIA, S. & ISTOOK, C. (2017). 'A Method to Create Body Sizing Systems'. *Clothing and Textiles Journal*. 35(4). pp. 235-248.

5 Journal Excerpts

Small Sampling Tests (Excerpt 5.1)

Posted: 7th September 2017

Although the double cloth element hasn't worked out, this batch of testing couldn't have gone much better. It has allayed my fears about not being able to weave accurately enough by hand. It has also produced some really great cloth. Doubling up the yarn in the heddles has given a dense but smooth cloth which is lightweight. The sett of the warp makes the cloth very stable - no floats that could get caught. I also think that the fabric has a sort of crispness that will mean it will cut cleanly, as well as not fraying too readily.

The combination of polyester, the density and the weave structure should make the fabric quite durable. In relation to this, I have been reading and writing about fabric durability for sustainability purposes - polyester is recognised as having good abrasion resistance as well as strength, as is the plain weave structure. This combined with the fact that the fabric will be 100% polyester and no additional fastenings will be required means that garment composition ticks quite a few of the sustainability boxes.

Tagged: *Design, Fashion, Sustainability, Functionality*

Exploring Design: Pattern and Panelling (Excerpt 5.2)

Posted: 7th January 2018

I have been looking at the hand woven trouser and thinking about the restrictions of the process and the structures that are possible. I really want to explore and demonstrate the possibilities of pattern and panelling in the Jacquard version. So I have looked at the panelling position and placement in a range of existing sportswear garments. Where panelling appears (which is predominantly on tights/leggings rather trousers) it is positioned across the hip, down the thigh and around the calf. Panels are described as adding breathable qualities as well as stretch. They also add aesthetic interest by being (generally) more open, with some placed in geometric blocks and others having a more contoured shape.

Going back through existing structure tests both from earlier in the PhD and from my MA, I have found examples of lace and waffle structures. The waffle provides stretch and shrink properties. The lace structures provide openness and mesh-like effects with some give in the cloth. The waffle and lace structures (PhD) have been tested in single cloth format and so need to be tested in double cloth as this is how the Jacquard trouser pattern will be produced. The testing was focussing on the shaping and functional possibilities rather than aesthetics/ design possibilities. However, samples from the MA used a different colour yarn in the weft (black) which gives a much stronger and graphic visual effect. When combined with the ecru warp the black weft knocks back the creaminess of the ecru. This makes the textile look much more 'designed' - less like a simple prototype or test. It accentuates the structure, this will visually highlight the shape of the panelling and the difference in the fabric qualities. So now I want to explore how the panelling and textile design will come together within the trouser to give visual impact in addition to their functional application.

To Do/Try Out

- *Map panelling position on pattern pieces*
- *Map text design onto pattern pieces – considering aesthetic qualities alongside functionality waffle and lace structure tests in double cloth on Jacquard*

Tagged: *Design, Design Aesthetics, Functionality, Idea*

6 Functionality:

Design Principles and Aesthetic Style

6 Functionality:

Design Principles and Aesthetic Style

6.1 Functionality: Chapter Overview

This chapter sets out the functionality principles (Section 6.2.1) applied in the design and construction of the six garment prototypes produced as part of this research. The principles operate in tandem with the sustainability principles outlined in Chapter 5. Together they are designed to ensure the functional durability (Section 6.3) and aesthetic desirability (Section 6.4) of the textiles and garments produced, by using the body (its anatomy, movements and needs) as a starting point for design. The principles guided the design, development and production of the garments, and focus upon the facilitation of movement and temperature management to optimise comfort and fit and capitalise on the simultaneous construction of textiles and garments offered by the Composite Pattern Weaving (CPW) system. They build upon my well-established personal design style (Section 6.2.2) - which combines the panelling of multiple weave structures with vibrant accent colours and geometric patterns that accentuate the characteristics and qualities of weave structures and materials.

6.2 Function in Fashion

The functional capacity of clothing is dictated by material innovation and developments in construction technologies; for example, the introduction of Lycra revolutionised fashion by enhancing the comfort and fit of clothing (O'Connor 2010). Over the last century, developments and innovations in synthetic, natural, hybrid and renewable fibres (Ibid), along with alternative forms of production such as three-dimensional knitting and thermo-welding of fabrics to produce seamless fashion, afford new creative potential for designers, leading to an increasing level of functionality for the consumer (O'Mahony & Braddock 2002).

Advances in material performance and construction frequently originate in the sportswear industry, with leading sports brands developing products to give athletes a competitive edge (see Nike's Hyperwarm Flex 2014-2018 and Speedo's Fastskin c.2000-2015). These textiles and techniques make the transition to fashion, where designers are attracted to their technical aesthetic and new construction potential, and respond to an increasing demand for utilitarian and versatile fashion (O'Mahony & Braddock 2002).

This research focuses on the functional and aesthetic potential of woven structures and the simultaneous construction of textile and garment; capitalising on the stability, durability and structural qualities of woven textiles to create women's garments for everyday wear. An exploration of the CPW system's ability to produce garments that are functionally durable and aesthetically desirable, for the purpose of extending the garments' usable and desirable life (Sections 5.8), is central to the research.

6.2.1 Functional Design Principles

The functional design principles applied in the research were developed to complement the sustainable design principles described in Section 5.3; to enhance garment longevity, facilitate end of life disposal, and minimise cutting waste and material production. They are designed to explore the interconnected areas of physical and emotional longevity (WRAP 2017) by focusing specifically on textile and garment functionality and the associated aesthetic characteristics. The principles are divided into two categories – functional durability and aesthetic desirability - to consider wear and tear, comfort and fit, colour, pattern and styling.

Functional Durability

The design of each textile and garment should have the:

- Ability to withstand wear and tear through choice of fibres and structures.
- Capacity to facilitate comfort and fit through cut, construction and composition.
- Flexibility in garment styling to accommodate changes in body shape and size.

Aesthetic Desirability

The design of each textile and garment should utilise:

- Modest garment design to achieve longevity and cross-seasonal appeal through the use of classic colours and simple styling.
- Functional application of patterns, colours and textures (rather than for superfluous decorative detail) to emphasise the inherent characteristics of the chosen materials and processes.

These principles are inspired by the philosophies of the Bauhaus weavers along with Constructivist and Japanese fashion design (Sections 6.4.1 & 6.4.2); approaches that value simplicity, quality of construction and materials, and functionality. They provide a framework for design that builds upon and extends my established design style/aesthetic (Section 6.2.2); demanding creative solutions to achieve a balance between garment functionality, sustainability and desirability.

6.2.2 Personal Design Style

Inspired by Bauhaus, Constructivist and Japanese design principles (Sections 6.4.1 & 6.4.2), functionality forms the basis of my textile design aesthetic. Throughout my Postgraduate studies (2013) and this research, I have developed a style that aims to balance functionality and visual impact, by celebrating the structure and geometry of woven construction (Figure 6.1). Designs are precise, geometric and minimalist, adopting a contemporary aesthetic that assimilates craft and technology, whereby textiles and garments are informed by and incorporate the technical and utilitarian elements often seen in functional and sports fashion, including the textile and garment features listed below:

Textile Features

- Vibrant accent colours
- Graphic geometric patterns
- Contoured and engineered panelling

Garment Features

- Drawstrings
- Pockets
- Soft deconstructed tailoring/shaping

Figure 6.1: Celebrating the Geometry of Woven Construction: MMAQ Residency Sampling (2018) and MA Geometeric Grayscale Collection (2013)
Photographs by Anna Piper

6.3 Designing with and for the Body

> Without the body, the garment can neither be entirely understood, nor fulfilled […] The living human, the body underneath, is a fundamental starting point and an ever present constant if one aims to develop new types of bodily expression […] If the pattern is nothing but the uncut fabric, the body ought to be included when explaining how a garment is put together.
>
> (Lindqvist 2013: 65)

The body, in this research, is central to garment design. Its shape, anatomy and movement guide design; with the body's relationship with the textile, the way it behaves on the body and responds to its biomechanical movements (Ibid), directing construction and the design aesthetic (or style). Garment designs exploit the functional and creative potential of simultaneous and seamless construction, mapping the body by intergrating multiple functions in a single layer of cloth to "respond to the specific needs of each body part." (Bramel 2015: 26), attained through engineered and seamless panelling of different textile qualities to form and fit garment components. There is a particular focus on optimising comfort and "good fit" (Watkins & Dunne 2015:17) by facilitating movement (Section 6.3.1) and considering temperature management (Section 6.3.2), achieved through garment styling and design features as well as textile composition and construction.

6.3.1 Designing with the Body: Movement

Movement, or the restriction thereof, is recognised as a critical factor in achieving comfort in clothing. Watkins and Dunne confirm that both textile characteristics and garment design contribute to ease of movement/mobility in clothing (2015: 59), whilst Ashdown states:

> Most clothing is designed for the 'anthropometric' position; that is, for a person standing squarely with feet slightly apart and arms at the sides.
>
> (2011: 278)

This approach to design does not allow for everyday or routine movements and activities (sitting and walking, for example). The range of movement required (or expected) by the wearer is clearly dependent on the activity being undertaken and the occasion/scenario for which the clothing is being worn (Ibid). As the body moves with or within a garment, the components of the body expand, contract, elongate and/or compress, and the garment is required to react accordingly. It is recognised that the rotational multi-planal movement of the shoulder and hip are instrumental in achieving mobility and comfort (Watkins & Dunne 2015; Watkins 2011). In particular, the shoulder has an extensive movement range (Ashdown 2011) and is considered problematic by designers (Watkins 2011), not least because many garments are suspended from the shoulder (Ashdown 2011). The single plane movement of the hinge joints at the elbow and knee are also areas of concern for the fashion designer.

> It is the combination of the right fabric with cut and construction techniques that makes the garment successful.
>
> (O'Mahony & Braddock 2002: 150)

Watkins and Dunne (2015) identify and rank the following fabric characteristics as being the most important in facilitating movement in clothing: stretch, flexibility, bulk/weight and friction. Stretchy, flexible, light-weight, thin and slippery fabrics are favoured for use in clothing, so that they move easily with the body. They also recognise that these qualities are not always available in materials that meet other functional requirements (e.g. durability, wear and tear, moisture regulation, waterproofing). Hosseini Ravandi and Valizadeh refer more specifically to the "constructional specification" (composition and structure) of fabrics, highlighting the importance and influence of "pattern of weave" and yarn count, particularly in relation to the thickness and weight of a fabric (2011: 74)[1].

Important factors to consider in garment design are ease, cut and fit. These elements can be defined as:

---

[1] The functional and durability characteristics of the weave structures used in the garment prototypes, along with the garment design features that contribute to durability and garment longevity are discussed in the sustainability chapter (Section 5.8.4) and listed in Tables 5.3 and 5.4. The characteristics of the specific yarn and structure combinations tested, along with their suitability for use in garment prototypes is discussed in detail in Chapter 7 (Section 7.3).

- **Ease:** the difference between the measurements of the body and the dimensions of the garment.
- **Cut:** the shape and contours of the garment and pattern pieces.
- **Fit:** the relationship between the garment form/shape (its ease and cut) and the body.

(Watkins & Dunne 2015: 61)

Stretch fabrics are credited with being "the most influential factor in cutting for mass produced garments" (Aldrich 2008: 7). Close-fitting clothing constructed using stretch fibres are frequently expounded as the most expedient way of facilitating movement and achieving comfort and fit (Watkins & Dunne 2015; Ashdown 2011; Taylor 1997), although they are not the only solution. Indeed, Lindqvist asserts that there is:

> [...] a perception that a well-fitted garment is one that accords to the shape of the wearer's body, creating a minimal number of creases while nonetheless allowing the body to move about comfortably. This understanding of fit is arguably one-dimensional and debatable, as it places little emphasis on the living body and its expressional and biomechanical qualities and demands.
>
> (2015: 74)

Methods including the insertion of gussets, vents and pleats, the use of openings and gathers as well as the insertion of flexible fabrics can be employed to maximise movement, whilst specific component styles such as the raglan sleeve are also credited with facilitating "maximum arm movement" (O'Mahony & Braddock 2002: 158). Changes in garment dimensions caused by bodily movements can be accommodated by adding width or length to garment components, whilst loose fitting garments can offer freedom of movement, as they can "make provision for the stretch that occurs over curved areas" (Taylor 1997:168). However, it is important to recognise that "movement can be prohibited by excess material as well as too little ease" (Watkins & Dunne 2015: 59), as fabric gathers, bunches and creases "will impede movement […] and create discomfort" (Ashdown 2011: 282).

	Design Measure	Design Impact
Keeping the body cool	• Use of fine fabrics to create thin garments	• Allowing air and water to pass through the structures so as not to trap air
	• Designing loose fitting garments	• Facilitating air circulation across and around the body
	• Use of open weave structures	• Allowing evaporation of moisture
	• Avoid layering fabrics within the garment (e.g. pockets, collars, facing)	• Allowing air and moisture circulation (as above)
	• Leave necklines open	• Allowing heat to dissipate (based on the principle that hot air rises)
Keeping the body warm	• Use of thick but lightweight fabrics	• Trapping small pockets of air to insulate
	• Use of layering systems (layering of garments and layering fabric within garments)	• Facilitating the building of air space and the combining of multiple functions
	• Insulating the core (heat, neck and torso)	• Preventing heat loss through application of insulation
	• Positioning of lighter insulation around joints	• To facilitate movement
	• Provision of openings and the ability to loosen components (e.g. sleeves)	• Preventing over-heating by providing air flow

Table 6.1: Practical Garment Design Measures to Regulate Temperature

The positioning of seams is also a critical factor in the construction and comfort of a garment, as poorly positioned seams (particularly underarm and side seams) can "chafe during repetitive movement" (Saifee 2009: 250). The minimisation and removal of seams can reduce the risk of discomfort through chafing, as well as reducing bulk and weight (O'Mahony & Braddock 2002).

6.3.2 Designing for the Body: Temperature Management

Another factor contributing to the comfort of clothing is the ability to regulate (or control) body temperature by facilitating air permeability, moisture management and, conversely, thermal insulation (Taylor 1997). Hosseini Ravandi and Valizadeh state:

> Physiological comfort is mainly related to maintenance of thermal and moisture balance of the body; in other words, it is the proper relationship between body heat and moisture production and loss.
> (2011: 62)

Watkins and Dunne (2015) give practical guidance for designing clothing and textiles to keep the body cool or warm (outlined in Table 6.1). These suggestions are based on a number of key principles, including:

- **Keeping the body warm:** insulating the body's core and guarding against overheating by providing ventilation.
- **Keeping the body cool:** allowing air to circulate around the body and exposing the skin and the body's core.

Weave structure and fabric composition both contribute to a garment's capacity to thermally insulate or allow for air permeability. For example, the waffle weave's[2] cellular construction facilitates the trapping of air to insulate the body, whilst structures like leno[3] and mock leno[4] are open and absorbent, allowing airflow and evaporation (Thomas 2009). Strategic placement (or zoning) of weave structures whose individual characteristics are "sympathetic to the needs of different areas of the body" (McCann et al. 2009: 255) can enhance garment performance and comfort.

---

[2] **Waffle:** the waffle (or honeycomb) structure is a float-based structure, with warp and weft floating on the face (front) and back of the cloth in a grid-like formation. The varying lengths and direction of the floats creates a 3D cellular effect as the floats contract when the fabric is removed from the loom and is finished.

[3] **Leno:** producing a light, open and sheer fabric, the warp threads are twisted around one another before the weft yarn is inserted creating an open grid formation. The twist holds the weft yarns in position, resulting in a stable but open mesh-like structure. The structure requires either specialist loom preparation or the use of leno heddles.

[4] **Mock Leno:** producing an open gauze-like fabric, the interlacing of the threads in the mock leno structure allows the warp and weft to move, distort and 'open-up' during finishing. Unlike the leno structure, the yarns are not twisted around each other and do not require specialised threading and loom preparation; the lack of twist means that that the structure is not as sheer or structurally stable as true leno.

Broadly speaking, synthetic fibres are favoured in garments intended for high intensity activities, due to their low moisture absorption and efficiency in wicking moisture away from the body (Watkins & Dunne 2015; Chaudhari, Chitnis & Ramkrishnan 2004), helping to keep the body cool. Of the natural fibres, wool is also deemed to have good wicking properties (Chaudhari et al. 2004), as well as providing insulation and breathability (Hosseini Ravandi & Valizadeh 2011), whilst cotton is breathable and cool (Ibid) but tends to absorb and retain moisture, leading to discomfort (Chaudhari et al. 2004). However, it is beyond the scope of this research to discuss in further detail the multiple individual elements that contribute to the inherent physical properties of fibres, yarns and woven structures (Song Ed. 2011; McCann & Bryson Eds. 2009; Corbman 1983 provide in-depth discussion and analysis).

> The ability to combine several capabilities in a single yarn is relatively new. Less than a decade ago this would not have been possible without reducing, or even destroying, the performance of one or both functionalities.
>
> (O'Mahony 2011: 32)

The engineering of fibres to alter, enhance and combine their inherent properties (see for example TECHMERINO™, Invista's Coolmax and Dupont's Kevlar), along with the development of complex constructions and finishing treatments, facilitates the production of high functioning textiles and clothing to regulate body temperature and provide comfort under extreme environmental conditions and during intense physical activity (Watkins & Dunne 2015; O'Mahony 2011; Chaudhari et al. 2004). Although developed specifically for their functionality, these new materials and construction techniques also offer designers new tactile and visual qualities (O'Mahony & Braddock 2002: 7) to work with.

6.3.3 Movement and Temperature Management: Informing Composite Pattern Weaving

The garment prototypes produced as part of this research are not intended to be specialist performance clothing – they are primarily functional fashion garments. As such, the technical principles relating to comfort and fit discussed in this section are used to guide, inform, inspire and evaluate designs, rather than being rigid requirements to be applied or adhered to. These functional principles, based on the needs of the

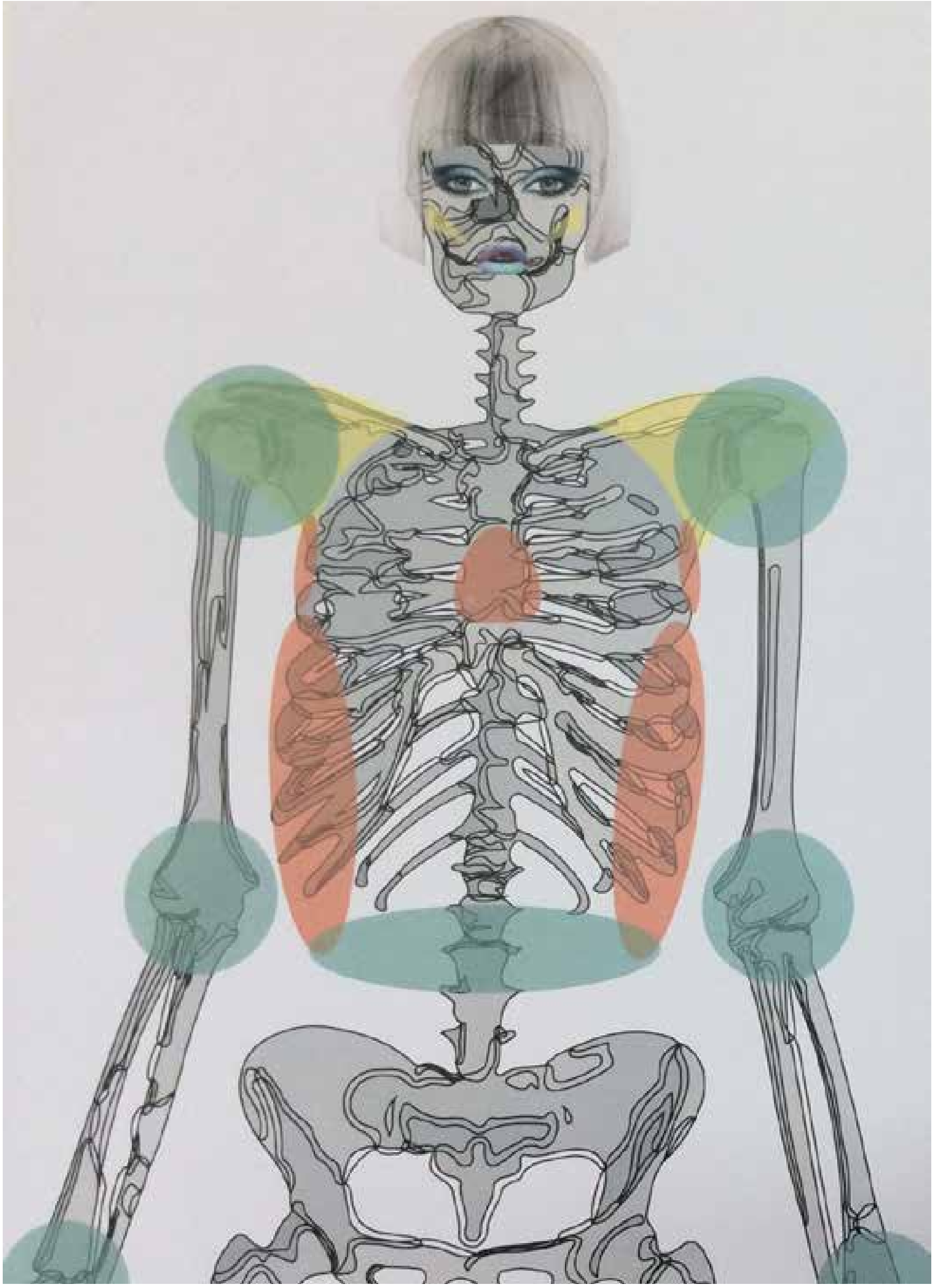


Figure 6.2: Joint Movements and Perspiration Patterns (2016)
Illustration by Anna Piper Based on Diagrams in Watkins & Dunne (2015)

body, are aligned with the principles of functional durability outlined in Sections 5.8.1 and 5.8.2. Together, they aim to cultivate garments that balance physical performance and desirability (wear and tear, comfort and fit) and sustainability (extending garment lifetimes and end of life disposal), by embedding these ideals throughout the design and production process. However, the ability to apply these functional and sustainable design principles is regulated and constrained by the mode of prodcution, with

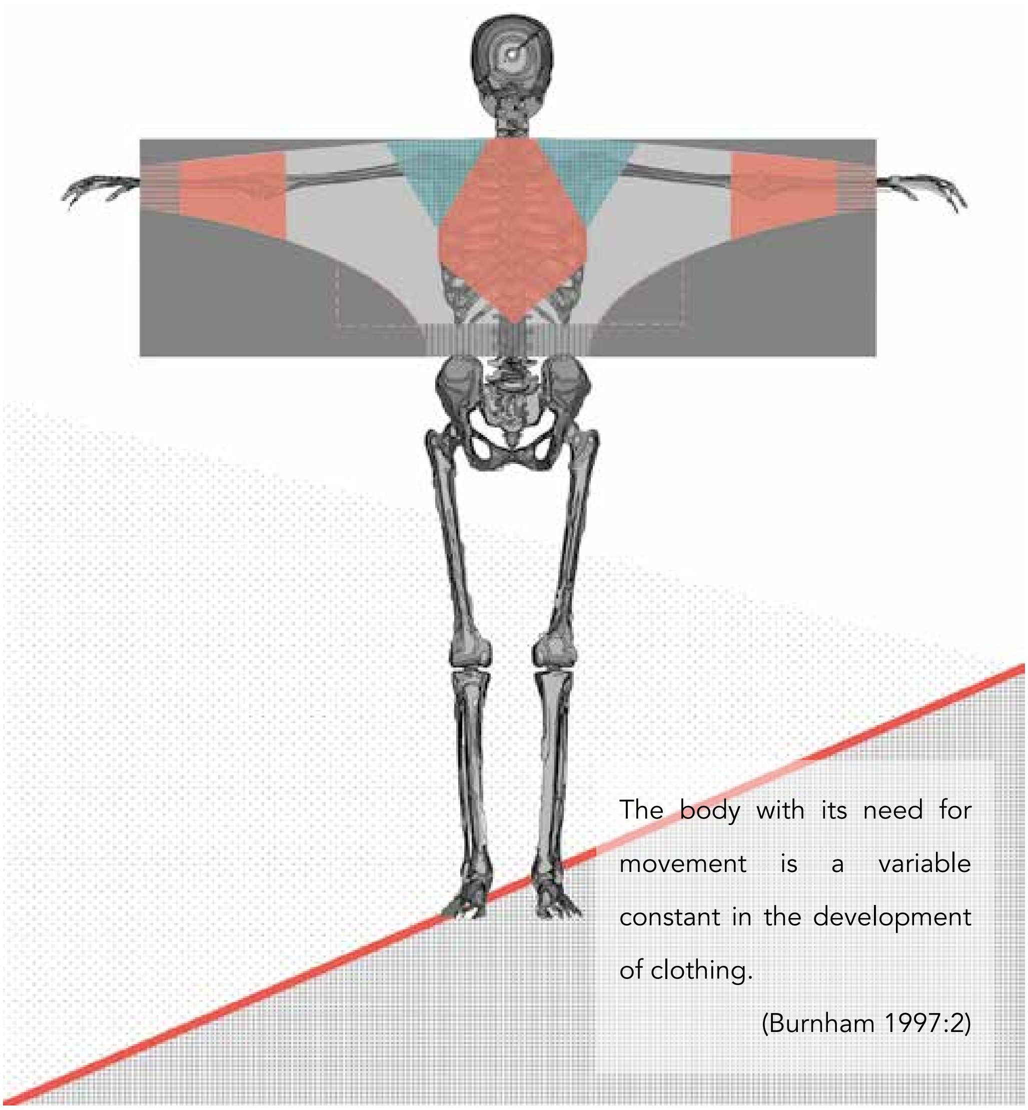


Figure 6.3: Top Design: Functional Panelling Positioning (2016)
Illustration by Anna Piper

compromises necessary, such as the need to accommodate predetermined warp widths and yarns.

The rotational and multi-planal movements of the joints and perspiration patterns (Figure 6.2) were used as a starting point for design; providing both visual inspiration and an anatomical template to inform the positioning of functional panelling (Figure 6.3). Principles and practical measures and methods to aid movement and comfort were included throughout garment design and textile composition. They directed garment styling, weave structure choices and material selection; all of which combined to form the overall design aesthetic.

> The development of these engineered […] woven structures, with their zones of contrasting fabric and yarn properties, provides garment functionality that is integral to aesthetic appearance.
>
> (McCann et al. 2009: 255)

The garment prototypes are relatively simple in design (but complex in their construction), with fashion design and functionality principles applied within the parameters of my limited fashion design capabilities (skills, experience and abilities). The garment prototypes are therefore aspirational – intended to showcase and suggest the potential of the CPW system for use in specialist performance construction and for fashionable clothing, incorporating advanced pattern and garment design techniques.

6.4 Function as a Design Aesthetic

The way the individual feels *about* a garment when they wear it and the way they feel *in* it is not entirely determined by physical comfort (or discomfort) (Hosseini Ravandi & Valizadeh 2011; Au et al. 2003). Personal stylistic preferences, fashion trends and a garment's appropriateness for a particular occasion or activity also have a role to play in the wearer's physical and psychological comfort (see Hosseini Ravandi & Valizadeh 2011) and the garment's aesthetic durability (see WRAP 2017) (Section 5.8.3). As such, aesthetic qualities such as colour, pattern and texture "are now seen as part of their function." (O'Mahony 2011: 19).

Au et al. (2003) identify "The aesthetic factor" as being one of four influential features that inform a fashion designer during the creative process[5]. This "aesthetic factor" refers to the aesthetic influence of artistic movements and cultural ideals of beauty from which designers draw inspiration to develop new ideas. Throughout my practice, I have been inspired by Modernist principles of design and the often quoted adage "Form follows function" (Sullivan in Guggenheim c.2018). This has precipitated a particular personal interest in Bauhaus weaving theory, Constructivist design and Japanese fashion design, which all embrace the notion that aesthetic qualities are derived from and informed

---

[5] In addition to the "aesthetic factor" Au et al. (2003) refer to the "historical factor", the "socio-cultural factor" and the "marketing factor" influencing and inspiring fashion designers' during the creative design process. Short descriptions of each of these factors can be found on pages 4 and 5 of their paper 'Grounded Design Theory of Japanese Fashion Designers'.

by functional ideals, with the functionality of a design (textile and/or garment) being intrinsic to the design aesthetic. This way of thinking is embedded in my approach to design and my personal design aesthetic through the application of functional and sustainable design principles. It has underpinned my aesthetic style and design decisions throughout this research (and throughout my design career as a whole); an approach that celebrates and capitalises upon the visual qualities of functional weave structures and the stylistic traits regulated by the mode of production.

6.4.1 Inspiration: Bauhaus Weaving and Constructivist Design

The communist ideology of Russian Constructivism promoted functionality and uniformity in dress. It prescribed strict anti-aesthetic utilitarian principles; clothing was designed for utility, not to enhance the appearance of the wearer. Functional concerns included comfort, durability and freedom of movement; for example, pocket position was based on the length of the arm (Stern 2004). Lamanova describes an approach to garment design that divides the body into geometric shapes to form the silhouette – "translating the body into surfaces" to complement the figure and address imperfections (Ibid: 174). Garments were simply and geometrically cut with the aesthetic style directly determined by their construction (see the work of Aleksandra Ekster and Liubov Popova in Stern 2004).

Bauhaus weaver Gunta Stolzl refers to the duality of a woven textile as an assemblage of distinct components and a unified surface (Smith 2014). Anni Albers attributed the beauty of their fabrics to "the clear use of the raw materials", with simple woven construction accentuating their inherent qualities through the avoidance of decorative detail (1961: 14). In describing the relationship between function and form, Albers states, "it is the coalition of form answering practical needs and form answering aesthetic needs" (Ibid. 2), in doing so she acknowledges the importance of aesthetic appeal and affirms that "good function is never enough" (Smith 2014: 63).

6.4.2 Inspiration: Japanese Fashion Design

Japanese fashion design is rooted in a reverence and respect for textiles, reflected in its oversized, untailored and adaptable styles; emphasising the "flat terrain of the cloth" to maintain the "integrity of the untailored textile" (Koda & Martin 2000), and using the shape of the textile to "house the body" (English 2011:15). Japanese clothing is "conceived in flat fields of cloth" (Martin 1995: 219) and deliberately disregards "natural" bodylines" (Kawlra 2002: 302). The Japanese kimono, with its simple geometric construction using multiple rectangles of cloth, continues to be highly influential in Japanese fashion design.

> It is the foundation on which they build their garments and conceptualize their ideas regarding space, balance and the relationship of the shape of the garment to the underlying body.
>
> (English. 2011: 4)

Adopting a postmodern sensibility and "visual arts framework" (English 2011: 9) that embraces and assimilates tradition, craftsmanship and technology (Bartlett 2000), Japanese designers Kawakubo, Miyake and Yamamoto have been credited with designing clothes that "break the boundary between the West and the East, fashion and anti-fashion, and modern and anti-modern" (Kawamura, 2004: 196). They have changed the shape of fashion by introducing garments that respond to and accommodate the movements of the body (Kawamura 2004; Martin 1995). Using layering, swathing and wrapping (Kawlra 2002: 300), and in Miyake's case extensive pleating, they form garments where the fabric and the body co-exist (Benaim 1997), through the creation of "space between the body and the cloth […] which creates a natural freedom, and general flexibility in the garment." (English 2011:21).

> Japan has provided the model of adaptability that has been required for functions of dress and for reasons of modern simplicity in life.
>
> (Martin 1995: 216)

The functionality of Japanese clothing is intrinsic to the design's success, with good design necessarily fulfilling the "the psychological needs of the wearer" (Au et al. 2003: 11) through their aesthetic qualities and their ability to "match people's lifestyle and personality" (Homma in Au et al. 2003: 20). Indeed, Issey Miyake views clothes as "tools for living that should be relaxing, convenient and useful." (English, 2011: 21), whilst Yohji Yamomoto's designs are recognised as being "imbued with functions of protection and durability" (Da Cruz 2000). They express an aesthetic style that is deceptively simple and elegant – combining unstructured (and deconstructed) oversized silhouettes, irregular asymmetric cuts, with monochromatic colour palettes, unfinished edges and intentional fabric flaws; working with innovative, natural and unconventional materials, and exploiting new technologies and traditional techniques.

> An interest in the evolution of fiber technology and a devotion to tonal and textural eclecticism prompts these designers to repeatedly emphasize the importance of their raw materials.
>
> (Ibid)

6.4.3 Influence: The Mode of Production

The limited number of shafts on the hand loom places restrictions on the production of different constructions and potential silhouette shaping strategies. Using sectional block threading, single cloth and single-piece or multi-piece construction, simple geometric shapes can be achieved. Digital Jacquard production (using the TC2 or power loom) affords greater shaping flexibility due to its single-end control, and complex curved shapes and panels, with multiple weave structure combinations, can be produced. In both cases, the warp provides a rectangular 'canvas' of predetermined width, presenting a significant challenge both for garment size and volume, as well as for efficient use to minimise waste.

The width of the warp determines the direction of weaving and the configuration of pattern pieces/garment components in the lay-plan. Furthermore, the production of zero waste lay-plans influences the proportions of garments and the application of additional functional design features (such as pockets and facings), with the shape and size of pattern pieces adjusted to fully utilise the rectangular length fabric. Single-piece and composite garment construction facilitates the production of continuous (uninterrupted) engineered functional panelling and patterns that map the body and respond to its physical needs. Whilst multi-piece construction presents opportunities to deliberately differentiate between garment components to accentuate the garment silhouette and construction through the application of weave structures and colour.

In both craft and technical examples of fully-fashioned and composite garment weaving, the tendency has been to focus on the two extremes of unstructured draping silhouettes (see the work of Lottie Dalgaard (2012)) or elastic stretch-fit (see Wang et al. 2009) - properties that are more commonly associated with knitted textiles and garments (Section 4.6.2). This research challenges these existing approaches by exploiting the constraints of hand and digital weaving and capitalising on the conventions and inherent characteristics of woven construction; using them along with functional and sustainable design principles to create the design aesthetic and influence garment styling. As such, "Performance, comfort and styling are inextricably linked." (O'Mahony 2011: 193).

6.4.4 Application: Colour, Pattern and Structure

In CPW, form is generated through textile construction and composition; yarns and structures are selected for their functionality and shaping capabilities (Section 7.3). The complexity of constructing and shaping garments in this way can restrict opportunities to assimilate decorative patterns during production, particularly when working on the hand loom. Pattern is therefore generated as a consequence of functional weave structure selection and panelling; the aesthetic is integral to garment functionality. The patterns that feature in the garment prototypes can be categorised as:

1. **Functional:** generated by the requirements for a particular textile characteristic or property (such as durability, stretch or ventilation).
2. **Instructional:** colour and structure coding applied to guide the construction of the garment by indicating cut and fold lines, seam allowanced and hems.
3. **Enhancing:** colours or patterns applied to enhance the visual qualities of construction, achieve aesthetic impact and creative visual connections between garments.
4. **Transforming:** pattern transformed through manipulation or finishing treatment to alter structure of the cloth and integrally shape the garment.

Moving away from the textural hand-crafted aesthetic (attributed to the use of chunky natural fibres and neutral browns, creams and beiges) of the bespoke garments produced in the craft realm (see friends of light and Manonik (Section 4.3.1)) the garments produced in this research aim to achieve a sharper, more graphic contemporary aesthetic through the use of contrasting classic colours (black, grey, ecru and white), and bold geometric shapes to accentuate the qualities of yarns, weave structures and garment characteristics (Figure 6.4).

Figure 6.4: Dress Featuring Functional, Instructional, Enhancing and Transforming Patterns (2018)
Photograph by Anna Piper

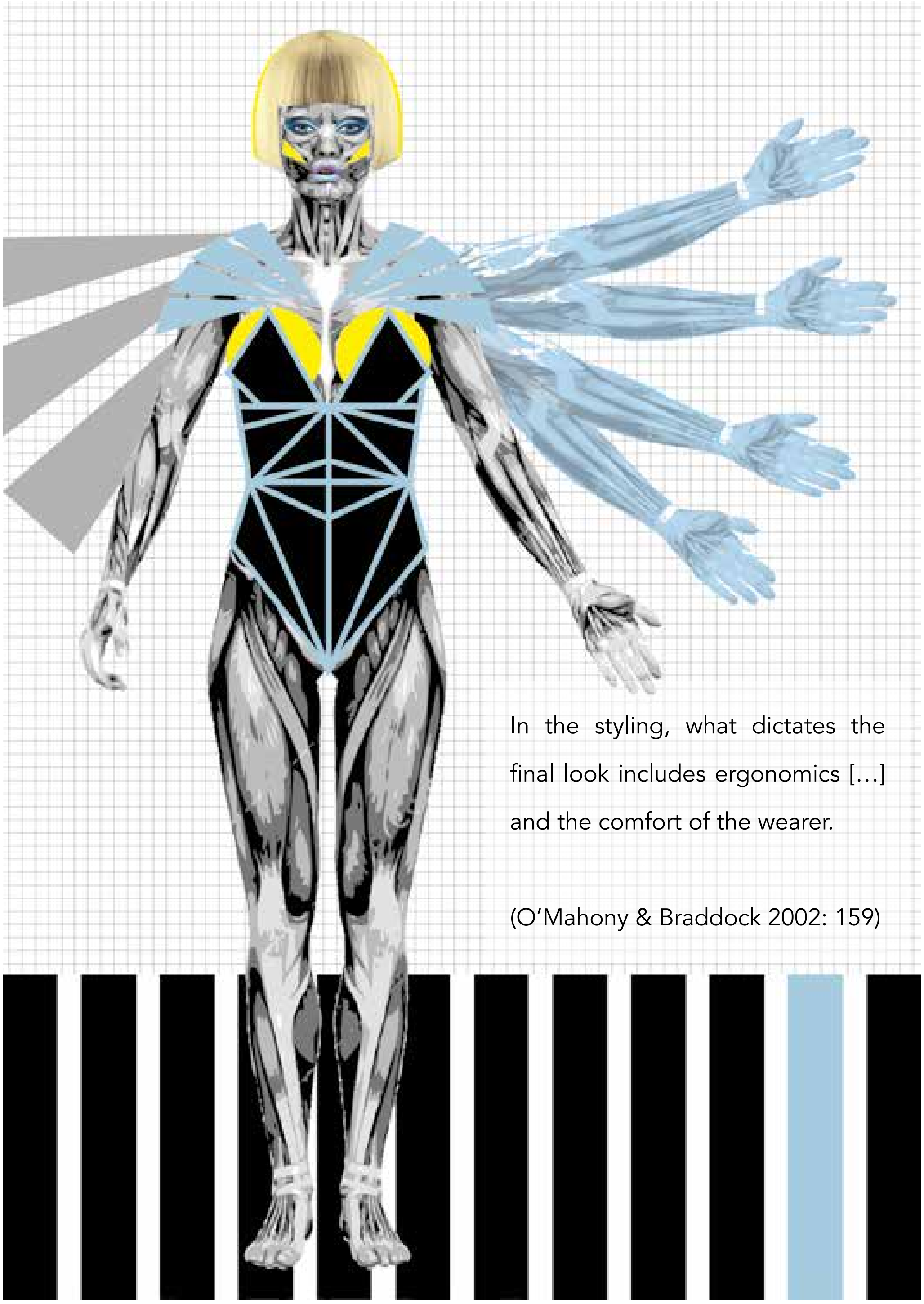


Figure 6.5: The Body and Its Movements as Visual Inspiration and a Template for Design (2014)
Illustration by Anna Piper

Using the body as visual inspiration and a template for design (Figure 6.5), the garment prototypes capitalise on and emphasise the functionality of the fabrics and garment styling (silhouette and fit), whereby the “contrasting fabric and yarn properties, provides garment functionality that is integral to aesthetic appearance.” (McCann et al. 2009: 255).

6.5 Functionality: Chapter Conclusion

This chapter has outlined and contextualised the functional design principles adopted throughout this research. These principles focus on optimising comfort and fit in the garment prototypes through the facilitation of movement and temperature management, both of which are contingent on textile composition and structure, as well as being influenced by garment silhouette and styling. In this research, these functional characteristics, along with the mode of production (hand, digital or hybrid weaving), form the basis of the design aesthetic, with colour, weave structures, yarns and patterns applied for functional (rather than decorative) reasons; the form of the garment is determined by its function, and the function of the garment is determined by the physical needs of the body/wearer.

The functional design principles supplement and complement the sustainable design criteria discussed in Chapter 5, with the aim of producing garments with functional durability, aesthetic desirability and longevity. Each garment prototype responds to and applies these principles in different ways and to varying degrees, through the application of weave structures, yarns, engineered panelling and integral shaping within the constraints of the mode of production. They have initiated the development and application of new techniques and processes; presenting technical and aesthetic challenges and opportunities that are addressed through incremental development and an iterative approach to design. The process has culminated in a collection of (functionally) interconnected garment prototypes; visually unified through shared usage of techniques and design features, whilst being distinct in their application and adaptation of methods (and principles) to suit the type of garment and its mode of production.

6.6 References

ALBERS, A. (1961). *Albers: On Designing*. Connecticut: Wesleyan University Press.

ALDRICH, W. (2008). *Metric Pattern Cutting for Women's Wear*. (5th Edition). Oxford: John Wiley & Sons.

ASHDOWN, S, P. (2011). 'Improving Body Movement Comfort in Apparel'. In: SONG, G. (Ed.). *Improving Comfort in Clothing*. Cambridge: Woodhead Publishing. pp.278–302.

AU, J, S. TAYLOR, G. & NEWTON E, W. (2003). 'Grounded Design Theory of Japanese Fashion Designers'. *The Design Journal*. 6(3). pp.3-23.

BARTLETT, D. (2000). 'Issey Miyake: Making Things'. *Fashion Theory: The Journal of Dress*. 4(2). pp. 223–227.

BENAIM, L. (1997). *Fashion Memoir: Issey Miyake*. London: Thames & Hudson.

BRAMEL, S. (2005) 'Key Trends in Sportswear Design'. In: Shishoo, R. (Ed.). (2005). *Textiles in Sport*. Cambridge: Woodhead Publishing in Textiles. pp. 25-43.

CHAUDHARI, S, S. CHITNIS, R, S. & RAMKRISHMAN, R. (2004). 'Waterproof Breathable Active Sports Wear Fabrics'. *Sasmira*. Available at: http://www.sasmira.org/sportwear.pdf. Accessed: 2 July 2015.

CORBMAN, B, P. (1983). *Textiles: Fiber to Fabric*. (6th Edition). London: McGraw-Hill.

DA CRUZ, E. (2014). 'Miyake, Kawakubo, and Yamamoto: Japanese Fashion in the Twentieth Century'. *Metropolitan Museum of Art: Heilbrunn Timeline of Art History*. Available at: http://www.metmuseum.org/toah/hd/jafa/hd_jafa.htm. Accessed: 13 March 2015.

DALGAARD, L. (2012). *Magical Materials to Weave: Blending Traditional & Innovative Yarns*. Translated by Ann Richards. Vermont: Trafalgar Square Books.

ENGLISH, B. (2011). *Japanese Fashion Designers: The Work and Influence of Issey Miyake, Yohji Yamamoto and Rei Kawakubo*. Oxford: Berg.

FERRIER, M. (2015). 'Forget "Athleisure" – Here's How to Look Chic in a Tracksuit'. *The Guardian*. Available at: http://www.theguardian.com/fashion/2015/mar/10/ athletic-lesiure-sportswear-everyday-fashion-trend-2015. Accessed: 15 May 2015.

GUGGENHEIM. (c.2018). 'Form Follows Function'. *Guggenheim*. Available at: https://www.guggenheim.org/arts-curriculum/topic/form-follows-function. Accessed: 10 October 2018

HOSSEINI, R, S, A. & VALIZADEH, M. (2011) 'Properties of Fibers and Fabrics That Contribute to Human Comfort'. In: SONG, G. (Ed.). *Improving Comfort in Clothing*. Cambridge: Woodhead Publishing. pp.62–78.

KAWAMURA, Y. (2004). 'The Japanese Revolution in Paris Fashion'. *Fashion Theory*. 8(2). pp. 195-224.
KAWLRA, A. (2002). 'The Kimono Body'. *Fashion Theory*. 6(3). pp. 299-310.
KITAMURA, M. (Ed.). (2012). *Pleats Please Issey Miyake*. London: Taschen GmbH.
KODA, H. & MARTIN, R. (2002). 'Orientalism: Visions of the East in Western Dress'. *Metropolitan Museum of Art*. Available at: http://www.metmuseum.org/toah/hd/orie/hd_orie.htm. Accessed: 13 March 2015.
LINDQVIST, R. (2015). 'Kinetic Garment Construction: Remarks on the Foundations of Pattern Cutting'. (PhD Thesis). Boras: The Swedish School of Textiles, University of Boras.
LINDQVIST, R. (2013) 'On the Logic of Pattern Cutting: Foundational Cuts and Approximations of the Body'. (Licentiate Thesis) Boras: The Swedish School of Textiles, University of Boras. Available at: http://bada.hb.se/handle/2320/11957. Accessed: 09 January 2015.
MARTIN, R. (1995). 'Our Kimono Mind: Reflections on Japanese Design: A Survey Since 1950'. *Journal of Design History*. 8(3). pp. 215-223.
MCCANN, J. & BRYSON, D (Eds.). 2009. *Smart Clothes and Wearable Technology.* Cambridge: Woodhead Publishing in Textiles.
MCCANN, J. MORKSKY HAMK, S. & DONG, X. (2009). 'Garment Construction: Cutting and Placing of Materials'. In: MCCANN, J. & BRYSON, D. (Eds.). (2009). S*mart Clothes and Wearable Technology.* Cambridge: Woodhead Publishing in Textiles. pp.235–261.
O'CONNOR, K. (2010). 'How Smart Is Smart? T-Shirts, Wellness, and the Way People Feel about "Medical" Textiles'. T*extile: The Journal of Cloth and Culture*. 8(1). pp. 50–67.
O'MAHONY, M. (2011). *Advanced Textiles for Health and Wellbeing*. London: Thames & Hudson.
O'MAHONY, M. & BRADDOCK, S, E. (2002). S*portsTech: Revolutionary Fabrics, Fashion and Design*. London: Thames & Hudson.
SAIFEE, F. (2009). 'The Influence of Knitwear on Smart Wearables'. In: MCCANN, J. & BRYSON, D. (Eds.). (2009). *Smart Clothes and Wearable Technology*. Cambridge: Woodhead Publishing in Textiles. pp.111–130.
SMITH, T. (2014). *Bauhaus Weaving Theory: From Feminine Craft to Mode of Design.* London. University of Minnesota Press.
SONG, G. Ed. 2011. *Improving Comfort in Clothing*. Oxford: Woodhead Publishing Limited.

STERN, R. (2004). *Against Fashion: Clothing as Art, 1850-1930*. Cambridge: The MIT Press.

TAYLOR M, A. (1997). *Technology of Textile Properties*. (3rd Edition). London: Forbes Publications

THOMAS, L. (2009). 'Woven Structures and Their Impact in the Function and Performance of Smart Clothing'. In: MCCANN, J. & BRYSON, D. (Eds.). (2009). *Smart Clothes and Wearable Technology*. Cambridge: Woodhead Publishing in Textiles. pp.131–155.

WANG, X. NG, M, C, F. HU, J. & SZETO, Y, C. (2009). 'Shapeable Stretch Textiles via Simple Weaves for Seamless Woven Fashion'. *Textile Research Journal*. 79(18). pp.1715–1724.

WATKINS, S, M. & DUNNE, L, E. (2015). *Functional Clothing Design: From Sportswear to Spacesuits*. London: Bloomsbury.

WATKINS, P. (2011). 'Garment Pattern Design and Comfort'. In: SONG, G. (Ed.). (2011). *Improving Comfort in Clothing*. Cambridge: Woodhead Publishing. pp. 278–302.

WRAP. (2017). 'Sustainable Clothing: A Practical Guide to Enhancing Clothing Durability and Quality'. *WRAP.* Available at: http://www.wrap.org.uk/sites/files/wrap/Sustainable%20Clothing%20G uide%202017.pdf. Accessed: 20 September 2017.

7 Composite Pattern Weaving:

Technical Applications and Outcomes

7 Composite Pattern Weaving:

Technical Applications and Outcomes

7.1 Technical Application and Outcomes: Chapter Overview

This chapter focuses on the development of technical processes and garment prototypes. It begins with the classification of the types of woven production used in the research (hand, digital and hybrid) and goes on to outline the constraints and advantages of each mode of production, based on the looms' technical specifications and set-up (Section 7.2). The Component Construction and Garment Construction phases of the research are described in detail, with sections dedicated to recording and appraising the design, production and application of sustainable and functional design principles for each garment prototype.

7.2 Hand, Digital and Hybrid Weaving Approaches

This section describes the primary similarities and differences between hand, digital and hybrid weaving, before outlining the constraints and advantages of each mode of production when being used in CPW. It also provides full specification details of the looms used throughout the research.

7.2.1 Hand, Digital and Hybrid Weaving: Similarities and Differences

There are a number of elements that remain consistent across all forms of weaving. The warp promotes the production of rectangular lengths of cloth, and the loom determines the fabric width. Principles of construction, such as types of weave structure and their relationship with yarns and fabric density, remain consistent across all forms of production. In addition, the looms used in this research facilitate the simultaneous production of multiple fabrics (layered on top of each other).

The main differences between hand, digital and hybrid weaving relate to the mechanisms used to operate the lifting and lowering of threads on the loom. In this research two types of mechanism are used – Dobby and Jacquard. In Jacquard weaving each individual thread can be lifted independently, this is known as 'single-end control'. In Dobby weaving the loom has a fixed number of shafts, the warp ends are threaded onto the shafts in various combinations (depending on the warp design), and when a shaft is lifted all threads attached to that shaft will lift. As such, the threads are lifted in units and cannot be lifted independently. This affects the complexity of patterns, weave structure and garment lay-plans that can be produced using a particular loom. In addition to the lifting mechanism, the means of 'programming' the lifting of shafts (using digital programming or pegs and lags[1]), as well as the method of inserting the weft yarns, influences the types of fabrics and garments that can be produced. The effect of these differences, along with the advantages and constraints that they provide/impose on CPW are outlined in detail in Table 7.1.

The TC2 (hybrid) loom is a digitally programmed Jacquard loom with manual/hand weft insertion; as such, the loom bridges the gap between the hand loom and digital Jacquard power loom. The weaver gains the advantages of single-end control and the efficiency of digital programming, combined with the benefits of manual weft insertion and the material engagement of hand weaving.

7.2.2 Hand Weaving: AVL and George Wood Loom Specifications

Initial technical development (Component Construction phase) was undertaken on an AVL hand loom (Figure 7.1), and garment construction took place on a George Wood hand loom (Figure 7.2). Both looms utilise the same peg and lag Dobby mechanism and have similar specifications (illustrated in Tables 7.2 and 7.3), as such the constraints and advantages (Table 7.1) were consistent throughout the research.

[1] **Dobby Shaft Lifting Mechanism:** mechanical Dobby looms use a peg and lag system. Lags are small wooden batons with holes that are connected together and fed in to the Dobby head to control the lifting of the shafts. Each hole operates a shaft and each lag determines the lifting of shafts for a single pick. Pegs are placed in the holes, with a single peg serving to lift a single shaft.

Hand Construction		Digital Construction		Hybrid Construction	
Advantage	Constraint	Advantage	Constraint	Advantage	Constraint
• Freedom of yarn usage • Manual manipulation of yarns • Selective weaving of sections of the warp • Instant adjustment of density in response to yarns and weave structures • Hands-on engagement with material(s) and process(es) • Intuitive and responsive design	• Fixed number of shafts limits structure and pattern combinations and placement • Garment silhouettes (generally) restricted to angular geometric shapes • Limited speed of production • Variable consistency in construction (e.g. density and tension)	• Single-end control facilitating complex structure and pattern combination and placement • Single-end control facilitating complex garment silhouettes (including curves and contours) • Consistency of construction (e.g. density and tension) • Efficiency of production and digital programming	• Fixed number of shafts limits structure and pattern combinations and placement • Garment silhouettes (generally) restricted to angular geometric shapes • Limited speed of production	• Single-end control facilitating complex structure and pattern combination and placement • Single-end control facilitating complex garment silhouettes (including curves and contours) • Efficiency of digital programming • Freedom of yarn usage • Manual manipulation of yarns • Selective weaving of sections of the warp • Hands-on engagement with material(s) and process(es)	• The loom's predetermined set-up (i.e. harness) determines maximum pattern repeat and garment scale • Design and structure alterations require reprogramming • Limited speed of production • Variable consistency in construction (e.g. density and tension)

Table 7.1: Production Constraints and Advantages: Hand, Digital and Hybrid Construction

Figure 7.1: AVL Dobby Loom (2018)
Photograph by Anna Piper

Specification	
• Shaft operation	• 16 shafts
• Maximum weaving width	• 40 inches
• Maximum repeat width	• Variable based on yarn count and threading
• Weft insertion	• Manual shuttle insertion
• Warp yarn	• Variable to suit the garment design
• Warp density	• Variable based on yarn count

Table 7.2: AVL Dobby Loom Specification

Figure 7.2: George Wood Dobby Loom (2018)
Photograph by Anna Piper

Specification	
Shaft operation	16 shafts
Maximum weaving width	46 inches
Maximum repeat width	Variable based on yarn count and threading
Weft insertion	Manual shuttle insertion
Warp yarn	Variable to suit the garment design
Warp density	Variable based on yarn count

Table 7.3: George Wood Dobby Loom

Figure 7.3: Bonas Sample Master Digital Jacquard Power Loom (2018)
Photograph by Anna Piper

Specification	
• Shaft operation	• Single-end control
• Maximum weaving width	• 36.7 inches (including 0.5 inch selvedge on both sides of the warp)
• Maximum repeat width	• 11.9 inches (repeated 3 times across the warp width)
• Weft insertion	• Automatic rapier
• Warp yarn	• 30/2nm combed cotton (Ecru)
• Warp density	• 96 ends per inch (single cloth) • 48 ends per inch (double cloth)

Table 7.4: Bonas Sample Master Digital Jacquard Power Loom Specification

7.2.3 Digital Weaving: Bonas Sample Master Loom Specifications

The digital Jacquard power loom used in this research is a Bonas Sample Master (Figure 7.3), based at Nottingham Trent University. The loom is used in conjunction with Pointcarre weaving software. Working in an academic setting, a number of restrictions are placed on the research; the loom has a predetermined (unchangeable) warp (Table 7.4). Further constraints relating to the maximum pattern repeat within the width of the cloth are determined by the loom's triple-harness[2]. This provides the most significant challenge when designing garments for production on the Jacquard power loom – garments have to accommodate the triple pattern repeat across the width of the cloth within their design and construction (Sections 7.5 and 7.7).

7.2.4 Hybrid Weaving: TC2 Sample Loom Specifications

The TC2 Digital Jacquard Sample Loom with Modular Thread Controller (Figure 7.4) was acquired by Nottingham Trent University and introduced during the Garment Construction phase of the research. Like the Bonas Sample Master, the TC2 was used in conjunction with Pointcarre weave software to develop and programme designs. Again, working with this equipment in an academic setting the loom necessarily had a fixed warp yarn and specification (Table 7.5). Whilst this loom was not available for sampling during the Component Construction phase, the use of the same warp yarn (30/2nm combed cotton) with similar density on the Jacquard power loom meant that sampling outcomes were largely transferrable.

---

[2] **Triple-harness:** the Jacquard loom's harness mechanism controls the lifting and lowering of each warp thread. The Jacquard power loom being used in this research operates with a triple-harness containing 1152 warp threads in each harness. This is repeated three times across the width of the warp (3456 warp ends). A design can, therefore, contain a maximum of 1152, with the same design repeating three times across the width of the cloth/warp. It is not possible to control all 3456 warp ends on the warp independently to produce a fabric with a single repeat.

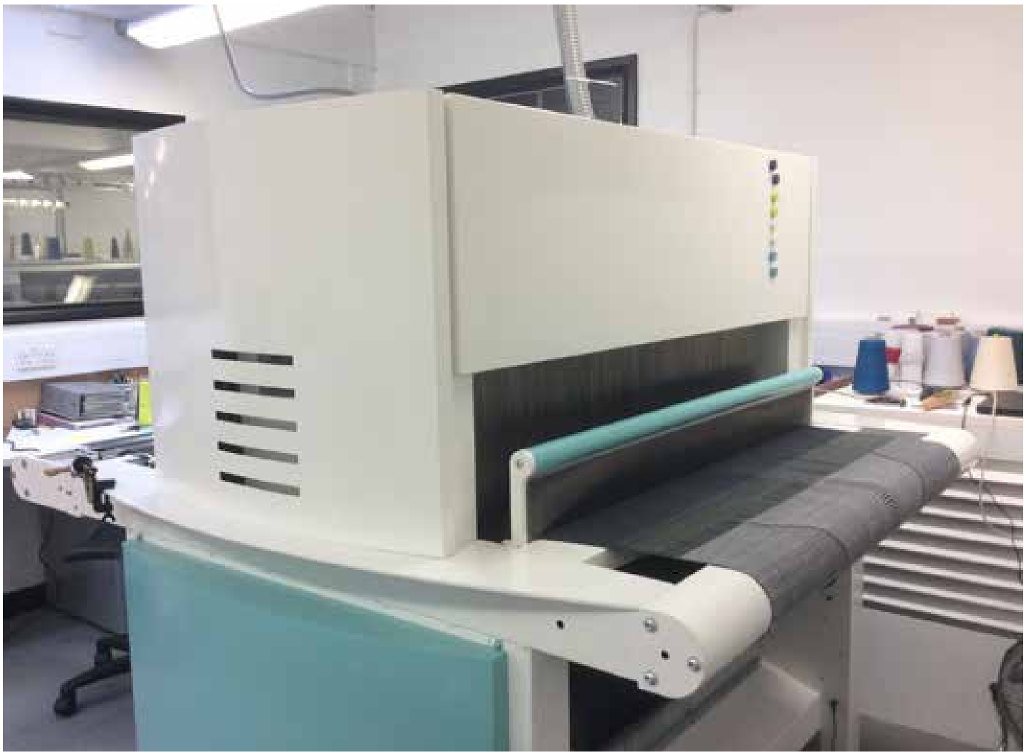


Figure 7.4: TC2 Jacquard Sample Loom with Modular Thread Controller (2018)
Photograph by Anna Piper

Specification	
• Shaft operation	• Single end control
• Maximum weaving width	• 42 inches
• Maximum repeat width	• 42 inches
• Weft insertion	• Manual Shuttle Insertion
• Warp yarn	• 30/2nm combed cotton (Ecru)
• Warp density	• 90 ends per inch (single cloth)
	• 45 ends per inch (double cloth)

Table 7.5: TC2 Jacquard Sample Loom with Modular Thread Controller Specification

7.3 Phase #1: Component Construction

The Component Construction phase of the research included hand and digital production. This technical development stage involved the systematic testing of a range of 'active' and 'passive' (synthetic and natural) yarns in combination with a variety of weave structures, to develop methods of integrally shaping woven fabrics and establish their suitability for application to garments (based on handle, appearance, reproducibility and flexibility of application). Each 'active' yarn and weave structure combination was tested with multiple 'passive' warp and weft yarns, with the level of

Figure 7.5: BA and MA 3D and Self-shaping Techniques (2012-2013)
Photographs by Anna Piper

activity (amount of shrink, stretch and structural manipulation) closely monitored and measured.

My past experience of working with 3D/self-shaping weaving techniques during my BA and MA studies (Figure 7.5), along with Richards' 'Weaving Textiles That Shape Themselves' (2012), Dalgaard's 'Magical Materials to Weave: Blending Traditional and Innovative Yarns' (2012) and Field's 'Collapse Weave' (2008) provided the starting point for experimentation. These texts supply detailed information on established techniques to 'shape' woven fabrics using yarn and structure manipulation.

The following sections provide an overview of key findings as well as examples of the different fabrics and techniques developed during the Component Construction phase of the research. Section 7.3.1 focuses on hand woven construction. Section 7.3.2 details the outcomes of digital testing. However, no production took place on the hybrid TC2 loom during this stage of the research[3]. Full details of all technical and developmental sampling can be found in Appendix 5.

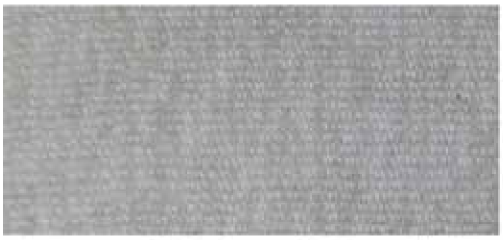
7.3.1 Sampling Outcomes: Hand Construction

The 'active' yarns being tested were categorised as high twist, stretch, permanent (or solid) shrink and thermosetting; they consist of natural and synthetic fibres and included wool, cotton, polyester and Lycra. The images that follow (Figures 7.6 - 7.8) depict the techniques, weave structure and yarn combinations tested on the hand loom during the Component Construction phase. The figures detail the composition, functionality, flexibility of application and analysis of relevant aesthetic qualities, as well as providing reflections on the process of construction and ideas development as a result of material and process engagement.

A small number of techniques, structures and yarn combinations were eliminated during the technical testing process, as they were deemed to be unsuccessful or unuseable due to ineffective shaping (see 3D fold and pleat samples in Figure 7.7) and/ or inappropriate handle (unstable, rough) (see sample including 5x85 Denier Silk with 20% Elastomer in Figure 7.6). On completion of the Component Construction phase, outcomes, techniques and 'active' yarns were categorised with the most successful selected for further development and garment application (Section 7.3.3).

---

[3] The hybrid TC2 loom was not available for use during the Component Construction phase of this study. See Section 4.7 for details relating to the acquisition of the TC2 and the implications this had for the progress and focus of the research.



Yarn(s): 27 Tex Polyester and 5x85 Denier Silk/12% Elastomer

Structure(s): Plain Weave

Function: No function, no further development - exceptionally rough handle

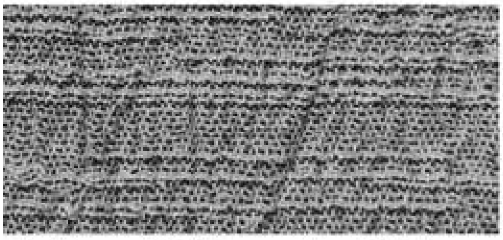
Aesthetics: Rough, regular and matt textured effect

Yarn(s): 27 Tex Polyester and14.5nm High Twist Merino

Structure(s): Plain Weave

Function: Fullness control

Aesthetics: Fine, uneven and multi-directional pleating and folding



Yarn(s): 27 Tex Polyester and Viscose Body Elite

Structure(s): Plain Weave

Function: Comfort fit

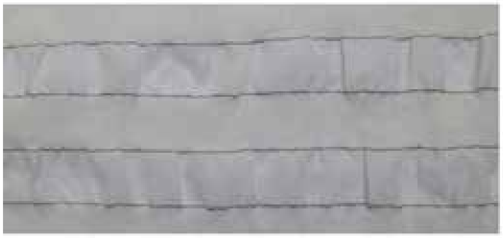
Aesthetics: Smooth, lustrous compact and consistent

Yarn(s): 27 Tex Polyester and Lycra

Structure(s): Plain Weave

Function: Soft weak stretch for comfort - not suited to shaping or hold

Aesthetics: Accentuated tracking giving a textural effect

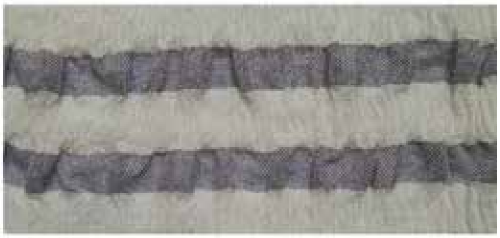


Yarn(s): 27 Tex Polyester and 60/2 Shrink Polyester

Structure(s): Plain Weave

Function: Movement facilitation and temperature regulation

Aesthetics: Light, open and smooth cloth with elegant ripples

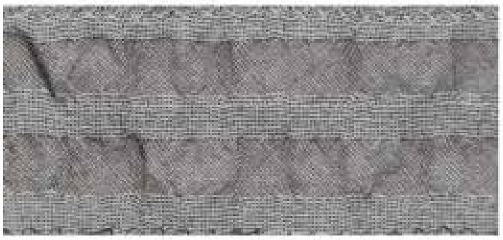


Yarn(s): 27 Tex Polyester and 14.5nm High Twist Merino

Structure(s): Plain Weave

Function: Shaping, fullness control and movement facilitation

Aesthetics: Surface contrast and texture with fine multi-directional folds

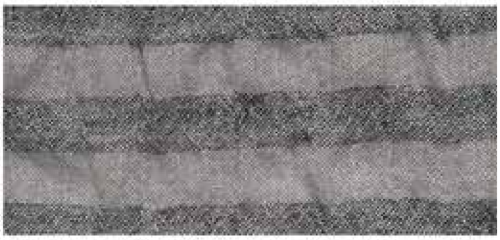


Yarn(s): 27 Tex Polyester and Lycra

Structure(s): Plain Weave

Function: Comfort stretch and fit

Aesthetics: Light open cloth with fluid seersucker and small-scale grid effect



Yarn(s): Tex Polyester and 30/1nm High Twist Wool

Structure(s): Plain Weave

Function: No function, no further development

Aesthetics: Mild undulation and tracking

Figure 7.6: Technical Samples: Plain Weave and Horizontal Seersucker (2015)
Photographs by Anna Piper

Yarn(s): 27 Tex Polyester, 50s Linen (right only) and 60/2 Shrink Polyester

Structure(s): Corded (Box) Pleat - Plain Weave

Function: Movement facilitation, fullness control and structure

Aesthetics: Strong neat pleat with clean edges
Light and fine with clear striping

Yarn(s): 27 Tex Polyester and 52/2 High Twist Wool

Structure(s): Corded (Knife) Pleat - Plain Weave

Function: Movement facilitation, fullness control and structure

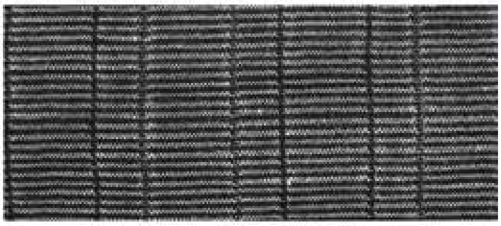
Aesthetics: Strong neat pleat with clean edges
Smooth, soft and dense

Yarn(s): 27 Tex Polyester and Lycra

Structure(s): Corded (Knife) Pleat - Plain Weave

Function: Movement facilitation, fullness control and comfort stretch

Aesthetics: Subtle bubbled texture
Light, fine and slightly uneven pleat

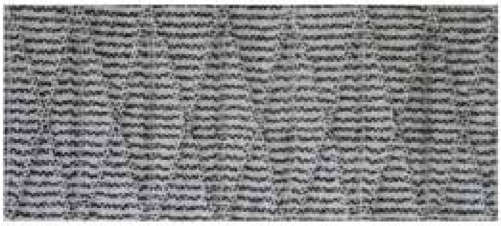


Yarn(s): 27 Tex Polyester, 50s Linen and 30/1nm High Twist Wool

Structure(s): Corded (Box) Pleat -Plain Weave

Function: No function, no further development - pleating not achieved

Aesthetics: Smooth, soft and dense with clear striping

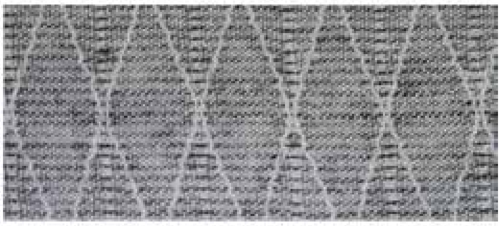


Yarn(s): 27 Tex Polyester and 60/2nm Shrink Polyester

Structure(s): Plain Weave Extra/Figurative Weft

Function: No function, no further development

Aesthetics: Subtle diamond relief
Fine with subtle striping



Yarn(s): 27 Tex Polyester and 30/1nm High Twist Wool

Structure(s): Plain Weave Extra/Figurative Weft

Function: No function, no further development

Aesthetics: Fine and clear diamond pattern
Subtle untidy stripe

Yarn(s): 2/16 Mercerised Cotton, 60/2nm Silk and Lycra

Structure(s): Plain Weave

Function: No function, no further development - no pleating

Aesthetics: Bold lustrous vertical stripes with fine subtle horizonal stripe

Yarn(s): 2/16 Mercerised Cotton, 60/2nm Silk and 60/2nm Shrink Polyester

Structure(s): Plain Weave

Function: Full and panelled shaping but not pleating

Aesthetics: Bold lustrous vertical stripes with textured bubble effect

Figure 7.7: Technical Samples: Corded Pleats, 3D Folds and Pleats (2015)
Photographs by Anna Piper

Yarn(s): 2/16 Mercerised Cotton and 60/2nm Shrink Polyester

Structure(s): 3/1 Twill and Plain Weave

Function: Shaping and fullness control

Aesthetics: Vertical compact rib with alternate smooth and textured stripes

Yarn(s): 2/16 Mercerised Cotton and 52/2nm High Twist Wool

Structure(s): 3/1 and 1/3 Twills

Function: Fullness control, shaping and stretch

Aesthetics: Soft edge pleat with deep ridge and textured boucle surface - no further development due to appearance

Yarn(s): 2/16 Mercerised Cotton and Lycra

Structure(s): 3/1 and 1/3 Twills

Function: Shaping and stretch

Aesthetics: Vertical, lustrous rib with alternate smooth and textural stripes

Yarn(s): 2/16 Mercerised Cotton and 30/1nm High Twist Wool

Structure(s): 3/1 and 1/3 Twills

Function: Fullness control, shaping and stretch

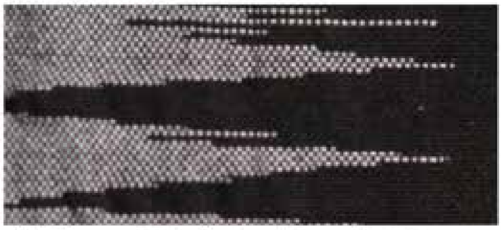
Aesthetics: Soft edge pleat with deep ridge
Lustrous surface with clean diagonal pattern

Yarn(s): 27 Tex Polyester and 60/2nm Shrink Polyester

Structure(s): Plain Weave and Clasped Weft

Function: Edge and integral shaping

Aesthetics: Light, fine and smooth, with contrasting panel and curved edge shaping

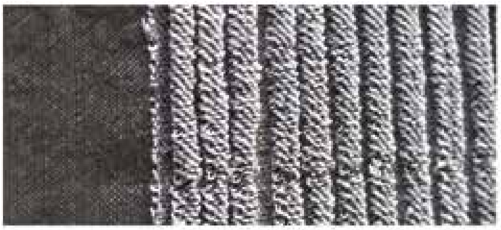


Yarn(s): 32/nm Merino and Viscose Body Elite

Structure(s): Plain Weave and Clasped Weft

Function: Comfort stretch

Aesthetics: Graphic contrasting panels
Soft dense surface



Yarn(s): 27 Tex Polyester and Lycra

Structure(s): 3/1 and 1/3 Twills with Clasped Weft

Function: Shaped and contoured panelling, fullness control and comfort stretch

Aesthetics: Contrasting flat and pleated panels
Textural, boucle with deep rounded pleats

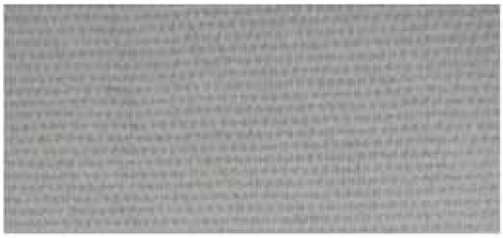
Yarn(s): 27 Tex Polyester, 32/nm Merino and 30/1nm High Twist Wool

Structure(s): 3/1 and 1/3 Twills with Clasped Weft

Function: Shaped and contoured panelling, fullness control and comfort stretch

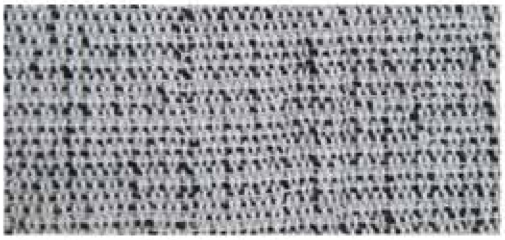
Aesthetics: Contrasting flat and uneven undulating panels

Figure 7.8: Technical Samples: Warp and Weft-facing Pleats and Clasped Weft (2015)
Photographs by Anna Piper

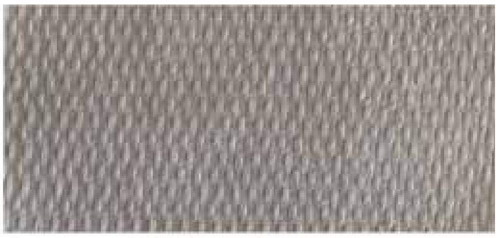


Yarn(s): 32/2ne Combed Cotton and Viscose Body Elite
Structure(s): Plain Weave (double cloth)
Function: Comfort fit
Aesthetics: Plain, smooth and dense cloth with slight lustre

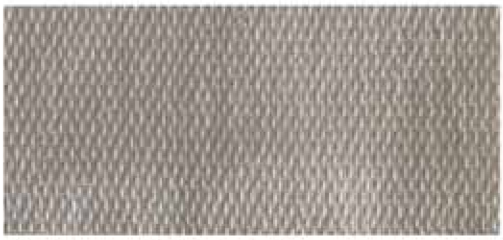
Yarn(s): 32/2ne Combed Cotton and 52/2nm High Twist Wool
Structure(s): Plain Weave (double cloth)
Function: No function, no further development
Aesthetics: Compact, dense cloth with mild and irregular vertical undulations



Yarn(s): 32/2ne Combed Cotton, 27 Tex Polyester and 60/2nm Shrink Polyester
Structure(s): Plain Weave (double cloth)
Function: No function, no further development
Aesthetics: Textured and rippled cloth with mottled effect



Yarn(s): 32/2 Combed Cotton
Structure(s): Mock Leno
Function: No function, no further development
Aesthetics: Dense compact fabric with small scale relief grid effect



Yarn(s): 32/2 Combed Cotton
Structure(s): 7 End Huck Lace
Function: No function, no further development
Aesthetics: Dense compact fabric with small scale relief grid effect

Yarn(s): 32/2 Combed Cotton
Structure(s): 5 End Huck Lace
Function: No function, no further development
Aesthetics: Dense compact fabric with small scale relief grid effect

Yarn(s): 32/2 Combed Cotton
Structure(s): 3 End Huck Lace
Function: No function, no further development
Aesthetics: Dense compact fabric with small scale relief grid effect

Figure 7.9: Jacquard Technical Samples: Plain Weave and Huck Lace (2015)
Photographs by Anna Piper

Yarn(s): 32/2 Combed Cotton

Structure(s): 31 End Waffle

Function: Integral shaping, panelling and stretch

Aesthetics: Deep fluid cellular fabric with thickness and bulk

Yarn(s): 32/2 Combed Cotton

Structure(s): 13 End Waffle

Function: Integral shaping, panelling and stretch

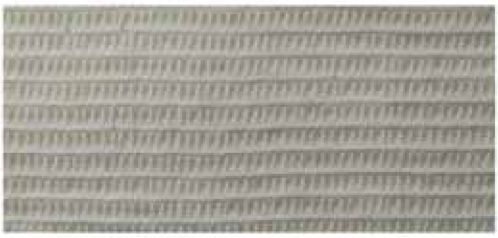
Aesthetics: Deep cellular fabric with thickness and bulk

Yarn(s): 32/2 Combed Cotton

Structure(s): 7 End Waffle

Function: Integral shaping, panelling and stretch

Aesthetics: Regular 3D rib with fluid and undulating floats



Yarn(s): 32/2 Combed Cotton

Structure(s): 5 End Waffle

Function: Integral shaping, panelling and stretch

Aesthetics: Regular semi-ribbed effect, with compact geometric relief

Yarn(s): 32/2 Combed Cotton

Structure(s): 13 End Waffle and 4/1 Basket Weave

Function: No function, no further development

Aesthetics: Contrasting panels of compact smooth cloth and fluid open cells

Yarn(s): 32/2 Combed Cotton

Structure(s): 13 End Waffle and 4/4Basket Weave

Function: Integral shaping, panelling and stretch

Aesthetics: Contrasting panels of compact smooth cloth and fluid open cells

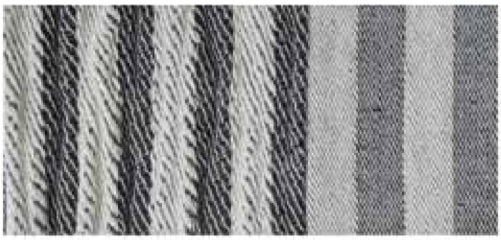
Yarn(s): 32/2 Combed Cotton

Structure(s): 13 End Waffle and 4/1Basket Weave

Function: No function, no further development

Aesthetics: Contrasting panels of compact smooth cloth and fluid open cells with mild undulation

Figure 7.10: Jacquard Technical Samples: Waffle Structures and Panels (2015)
Photographs by Anna Piper

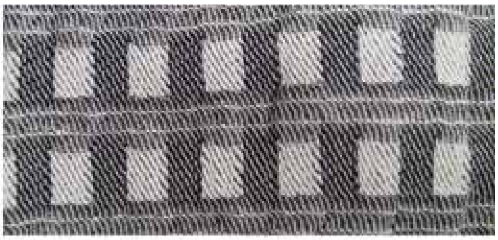


Yarn(s): 32/2 Combed Cotton and 52/2nm High Twist Wool

Structure(s): 1/7, 7/1, 1/3 and 3/1Twills

Function: No function, no further development

Aesthetics: Tonal vertical stripes with relief and mild rippled surface



Yarn(s): 32/2 Combed Cotton, 52/2nm High Twist Wool and 27 Tex Polyester

Structure(s): 1/7 and 7/1 Twills

Function: No function, no further development

Aesthetics: Bold blocks and stripes with textual relief

Yarn(s): 32/2 Combed Cotton and 52/2nm High Twist Wool

Structure(s): Plain Weave (double cloth) and Floats

Function: No function, no further development

Aesthetics: Textural cloth with subtle geometric pattern and fine stripes

Yarn(s): 32/2 Combed Cotton and 27 Tex Polyester

Structure(s): 4x4 Basket Weave (double cloth) and floats

Function: No function, no further development

Aesthetics: Not applicable

Figure 7.11: Jacquard Technical Samples: Warp and Weft-facing Pleats and 3D Folds (2015)
Photographs by Anna Piper

7.3.2 Sampling Outcomes: Digital Construction

Figures 7.9 – 7.11 show the techniques and fabric compositions explored when using the digital Jacquard power loom as part of the Component Construction phase of the research. All samples were constructed using a 30/2ne combed cotton warp with 96 EPI (single cloth) and 48 EPI (double cloth).

Table 7.5 provides further details of the yarns and structures tested on the digital Jacquard power loom, along with the machine's compatibility with the yarns and structure combinations (see Appendix 6 for further details), as this was a critical decision-making factor in the development of digital fabric and garment design and production. Furthermore, it highlights the impact of the different modes of production on the design development process.

As seen in Table 7.6, a number of the 'active' yarns, including 60/2nm polyester and Lycra, which provided effective results on the hand loom, were incompatible with the

	Weft Yarns									
Technique	60/2 Shrink Polyester	27 Tex Polyester	Viscose Body Elite	52/2 High Twist Wool	Lycra	60/2 Shrink Polyester & 27 Tex Polyester *	Grilon & 27 Tex Polyester*	Solvron & 27 Tex Polyester*	30/2ne Combed Cotton	30/1 High Twist Wool
Warp & Weft-facing Rib				X			X	X		X
Shibori Gather		X								
3D Folding (Extra Weft)		✓								
Plain Weave Shaping (Double Cloth)	X		✓	X	X	✓				
Waffle Cellular		✓							✓	
Weft/Loom Compatability	X	✓	✓	✓	X	✓	X	X	✓	X

* 'Active' yarns tested alone in the weft but found incompatible with the loom, subsequently tested coned together with 27 Tex Polyester and inserted as a single weft yarn.

Table 7.6: Component Construction: Digital Sample Composition Outcomes

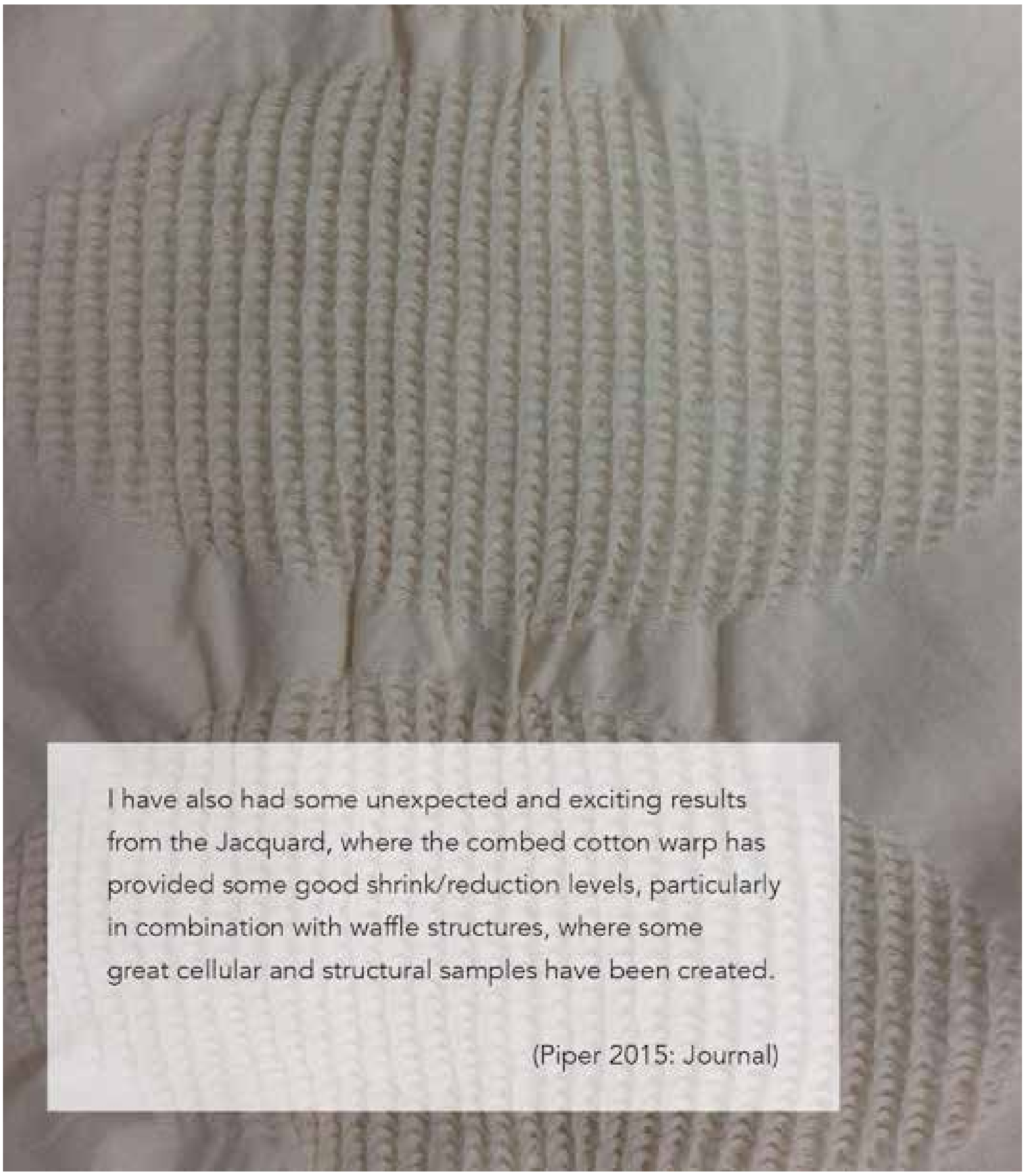


Figure 7.12: Unexpected Outcomes: Waffle Panels (2015)
Photographs by Anna Piper

Jacquard power loom and tests were necessarily abandoned. These yarns were not ultimately confined to use in hand woven garments, as they were utilised when the TC2 was introduced into the research to facilitate complex integral shaping of garments (see Section 7.9 – Garment #5: Top and Section 7.10 – Garment #6: Coat).

Whilst testing on the Jacquard power loom restricted yarn and structure usage (relative to hand woven construction), unexpected shaping effects were achieved when working with waffle weave structures composed entirely of 30/2ne combed cotton (Figure 7.12). The combed cotton had been categorised as a 'passive' yarn (a balanced yarn that remains structurally unchanged when finished) but, in combination with the

Figure 7.13: Fabric Types: Self-pleating, Panelling and Cellular Structures (2015)
Photographs by Anna Piper

cellular waffle structure, became 'active' (capable of providing both shrink and stretch properties). This fabric composition and shaping technique subsequently became the most flexible and frequently used in garment prototyping.

7.3.3 Technique Selection and Development

The textiles developed during this phase of the study present multiple flexible shaping and fitting options for application to woven garments that do not depend solely on stretch. Three distinct fabric types (Figure 7.13) were selected for progression to the Garment Construction phase of the research:

Self-pleat: a series of knife, box and undulating pleats created using corded and warp and weft-facing pleat techniques, applying high twist wool, shrink polyester and Lycra.

Panelling: multiple structure panelling facilitating strategic and seamless positioning of fabric qualities and functionality. This clasped weft technique is compatible with any yarn type but is restricted to use on the hand and TC2 looms.

Cellular Structures: particularly suited to production on the Jacquard and TC2 looms (due to the complexity and varying scales of structures), these functional cellular structures have both integral shaping and comfort fit potential due to their variable shrinkage and stretch properties.

Although a wide range of yarns produced successful outcomes in relation to potential fabric and shaping properties, they were narrowed down to six 'active' yarns to be applied to further technique development: 60/2nm shrink polyester, Lycra, 30/2ne combed cotton, 30/1nm high twist wool, 52/2 high twist wool and Viscose Body Elite. This selection was based on a number of factors: reliability and consistency of results, aesthetic appearance (including colour range availability), suitability for the mode of production, as well as yarn and textile characteristics (stretch, stability, permanent shrink). In addition, predominantly mono-fibres were chosen based on the sustainability aims and criteria of the research (Section 5.3.2). Warp yarns for hand construction and 'passive' weft yarns were not fixed at this stage, to avoid restricting the design process and limiting textile and garment outcomes. However, it was intended, where possible, to maintain the use of mono-fibres and to produce predominantly single-fibre textiles for recycling purposes (Section 5.9).

Ultimately, not all techniques, yarns and structures were utilised in the final garment prototypes, and some appear in multiple garments. Techniques, structures and yarns were selected and refined during the garment design process, in response to the requirements of the garment. As such, the textile and garment were designed simultaneously, rather than the textile determining the design of the garment or vice versa.

7.4 Phase #2: Garment Construction Overview

The second phase of the research focussed on the design and development of garment prototypes. The phase took place following the decision to concentrate on the production of composite pattern production rather than on composite garment weaving (Sections 1.4, 1.5 and 4.7). It brought together and applied some of the techniques developed in the Component Construction phase with the processes and garment construction methods established during my BA and MA studies (Sections 1.7 and 5.3.1), to produce a series of more advanced complex garments, by applying sustainable and functional design principles.

Six interconnected garment prototypes were designed and produced during this phase using the three modes of production – hand, digital and hybrid. The approaches, processes and outcomes are discussed in detail in the following sections of this chapter. They are presented in chronological order of final prototype production, rather than in

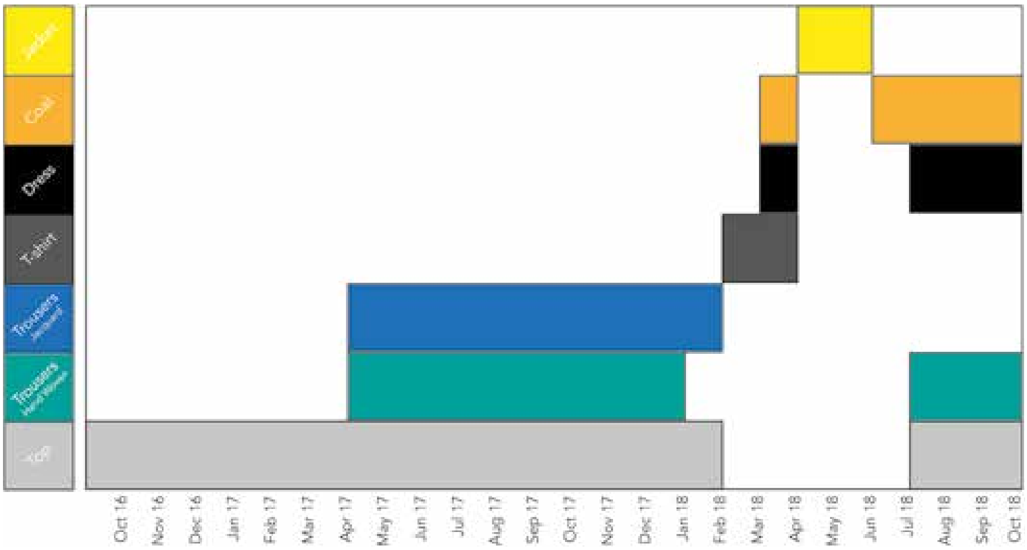


Figure 7.14: Garment Design and Construction Timeline (2018)
Illustration by Anna Piper

the order in which they were designed and developed. In order to test the Transitional Design Methodology and to establish the validity of the hypothesis that the integration of hand and digital methods through simultaneous (rather than linear) experimentation, design and production enhances innovation opportunities by stimulating and pushing the boundaries of both forms of production. Figure 7.14 shows the timeline of design development and production for the six garment prototypes.

To accommodate the delays in practice and production (discussed in Section 4.7) and in recognition of my limited fashion design experience and skills, a basic two-cut, two-seam geometric garment design/pattern was used as the basis for prototype development. This design was adapted and developed to suit the demands of the mode of production (e.g. maximum warp width and the use of 16 shafts or single-end control) and to demonstrate the capabilities, opportunities and possibilities of CPW.

The discussion and appraisal of technical processes and garment outcomes is accompanied by reflective journal excerpts and sketchbook annotations; capturing the evolution of ideas, thought processes and experiences of making.

7.5 Garment #1: Trousers

While the trousers were not the first to be designed, they were the first to be woven. It was, during their production that processes were established, and techniques were tested and rejected. The trouser design was the only one in the research to be applied to and developed for more than one construction method – a half-scale Jacquard trouser (Section 7.5.2) and full-scale hand woven version (Section 7.5.1) were produced. Ultimately, the hand woven trouser was found to be unsuccessful and production was abandoned before completion (Section 7.5.1). However, it was instrumental in the development of subsequent designs; informing decision-making and the advancement of the CPW concept (Section 7.5.5).

The lay-plan was developed from Aldrich's 'One-piece Trousers' (2008: 136) pattern using a standard pattern block. Conventional pattern cutting techniques, with multiple paper patterns and half-scale toiles were used to develop and refine the design and lay-plan, a multi-component (rather than a single-piece) zero waste lay-plan was produced by removing curves and adjusting dimensions to tesselate the pattern pieces. Designed in tandem, with the mode of production informing decision-making and the evolution of the designs by imposing constraints on their construction (including weave structure combinations, shaping techniques and design features (Sketchbook Annotation 7.1)), both the hand and digital versions incorporate integral shaping and panelling.

7.5.1 Design and Production Process: Hand Weaving

The pattern was developed at half-scale[4] with dimensions scaled up for hand weaving. It was not necessary to produce a full-scale paper pattern as the panel shaping could be calculated using basic pattern dimensions. The panel shaping calculation was adapted from a fashioning frequency calculation used in fashion knitwear for progressive edge shaping, which breaks down the garment component into sections, using the course per inch/centimetre (CPI/CPC), the wale per inch/centimetre (WPI/WPC) and the design dimensions to calculate the frequency of stitch reduction or increase (Spencer 2001).

---

[4] Reasons for designing at half-scale – time and economy (use of paper and fabric for toiles), availability of half-scale mannequin in the studio – not decided how the garment would be constructed – Jacquard/hand.

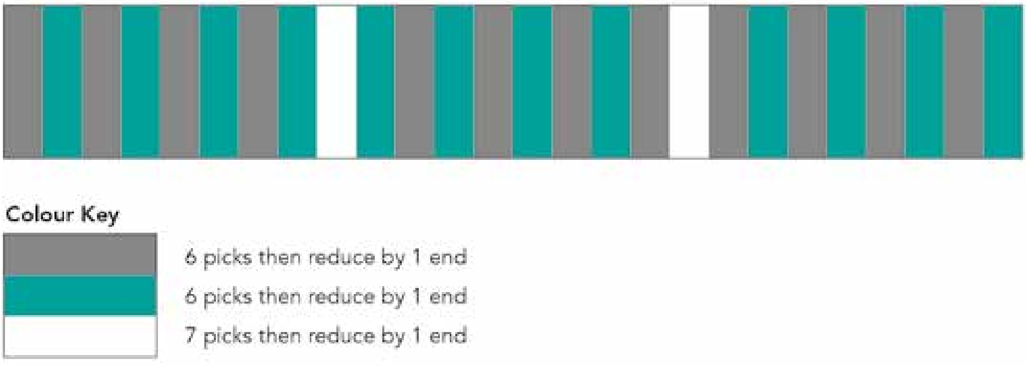


Figure 7.15: Trouser Panel Colour Coding System (2017)
Illustration by Anna Piper

A colour coding system (Figure 7.15) was devised alongside the shaping calculation and pattern development to assist in the construction and shaping of the gusset panels in particular; using colours to indicate the point of reduction or increase and to highlight how many picks were needed between each increase or reduction. The gusset panels were constructed using the clasped weft technique (Section 4.6.4, Figure 4.16), with two colours used in the weft – white for the gusset panels and grey in the leg panel). The colour coding was intended to mark the placement of the clasped weft, i.e. the point where the weft changed from grey to white, and vice versa.

As the calculation for panel shaping is based on warp and weft density, a series of small samples were produced to confirm the pick rate (picks per inch) and warp density (ends per inch), when working with the weave structures and yarn (27 Tex polyester) intended for use in the trousers. Despite this testing and the comprehensive colour coding, it was a lack of accuracy in the construction and shaping that eventually led to the abandonment of the hand woven trouser in mid-production. The process was extremely time consuming and, when weaving a much wider warp than was used in sampling, the number of picks being achieved per inch was not as planned. This resulted in the panel shaping being adapted during weaving, but the correct panel dimensions were still not achieved. The issues encountered during weaving (and during the loom set-up) are described in detail in Journal Excerpts 7.1, 7.2 and 7.3.

The complexity of the construction, the issues experienced during weaving and the lack of accuracy of the shaping process led me to question the viability and usefulness of the process (Journal Excerpt 7.4). As the clasped weft shaping was being applied purely to mark the shape of the gusset panel rather than to integrate different fabric

Figure 7.16: Hand Woven Trouser Production Process (2017)
Photographs by Anna Piper

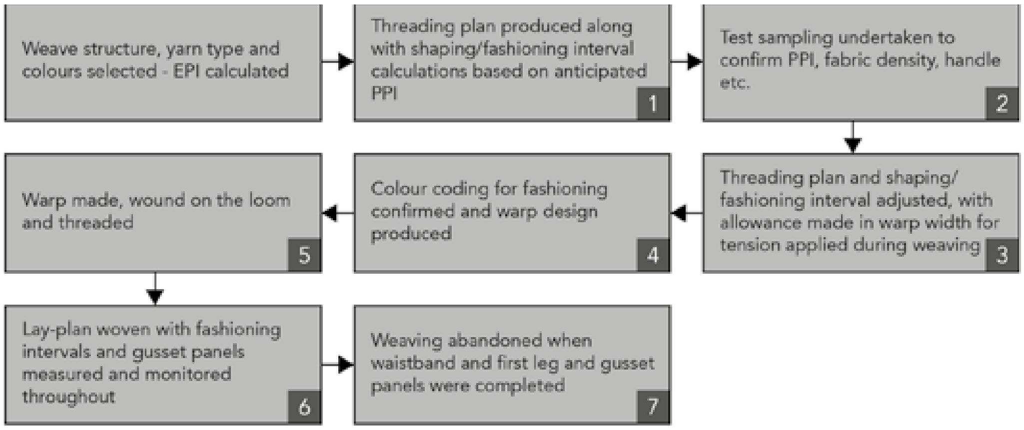


Figure 7.17: Hand Woven Trouser Production Process (2018)
Illustration by Anna Piper

qualities (through structure or yarn type) for enhanced functionality, the process and garment outcome did little to advance existing zero waste garments and processes – the same garment could be produced using a standard piece of fabric and a zero waste paper pattern. As a result, the garment was not completed, and the development of the digital Jacquard trouser was prioritised. Figures 7.16 and 7.17 capture the hand woven trouser production process.

7.5.2 Design and Production Process: Digital Weaving

As the trousers were the first design to be produced on the Jacquard power loom, there were a number of phases of development and technical experimentation to test, clarify and refine digitisation and production processes before the final garment was produced. These stages are described and illustrated in Figures 7.18 and 7.19.

Due to the Jacquard power loom having a triple-harness, resulting in a repeat across the width of the warp, it was not possible to produce the trousers at full-scale. The relatively simple half-scale geometric lay-plan was drawn directly into Pointcarre using the dimensions taken from the final version of the paper pattern, something that is not possible when digitising more complex garments (see the Top digitisation process in Section 7.9.1).

During the first production of the trousers it became evident that the Jacquard power loom's pick rate setting is not correctly calibrated – the pick rate on the dial does not match the number of picks being woven. Following numerous tests where the pattern scale was altered in Pointcarre, the lay-plan was re-woven but the dimensions were

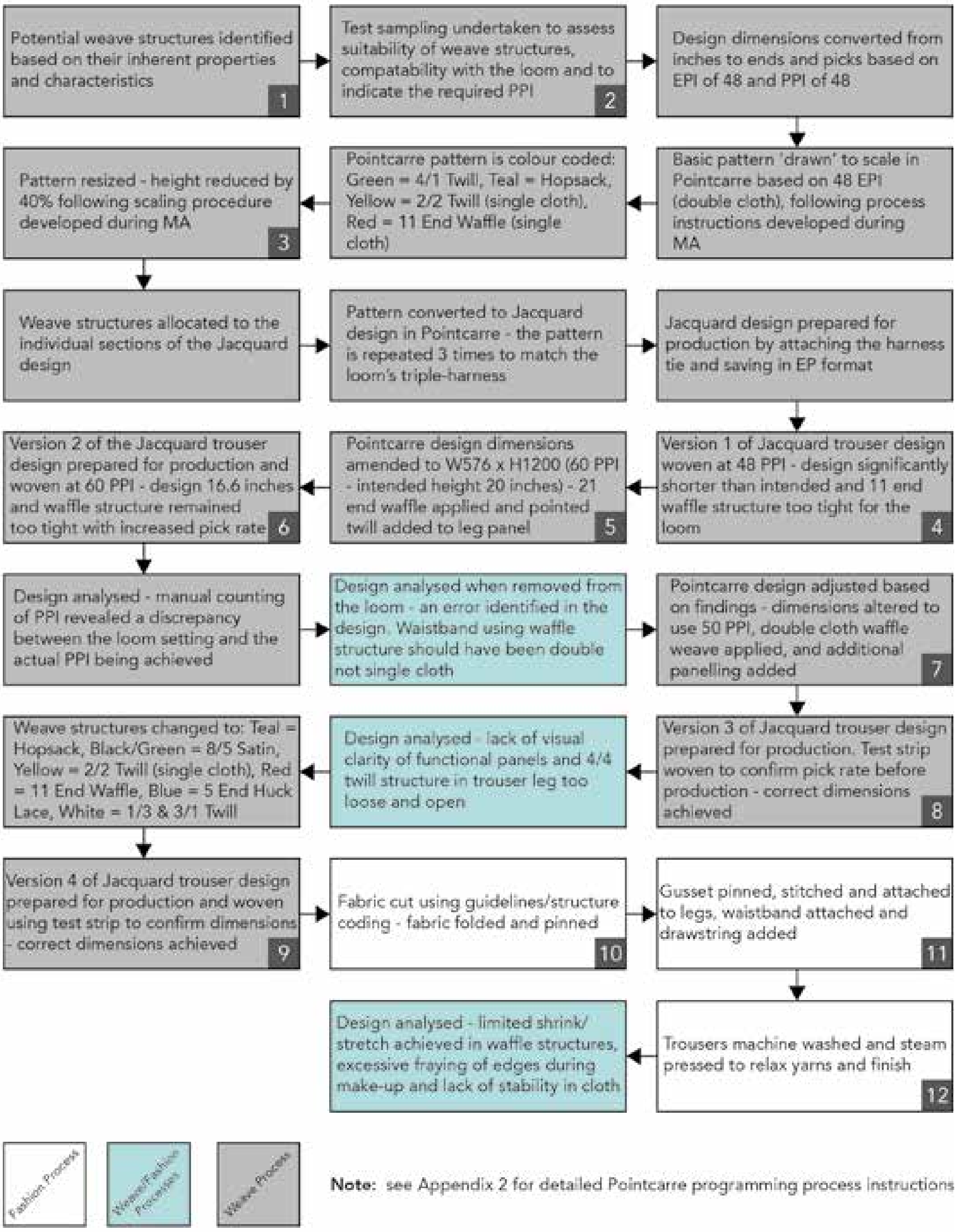


Figure 7.18: Jacquard Woven Trouser Production Process (2018)
Illustration by Anna Piper

repeatedly inaccurate, a process was devised to adjust the pick rate on the loom whilst weaving until the correct weft count (picks per inch) was achieved and the garment could be woven. Unfortunately, this leads to the production of waste fabric (Section 7.5.3). However, the process of testing and re-testing the lay-plan dimensions enabled other aspects of the design to be evaluated and refined. Weave structures were altered

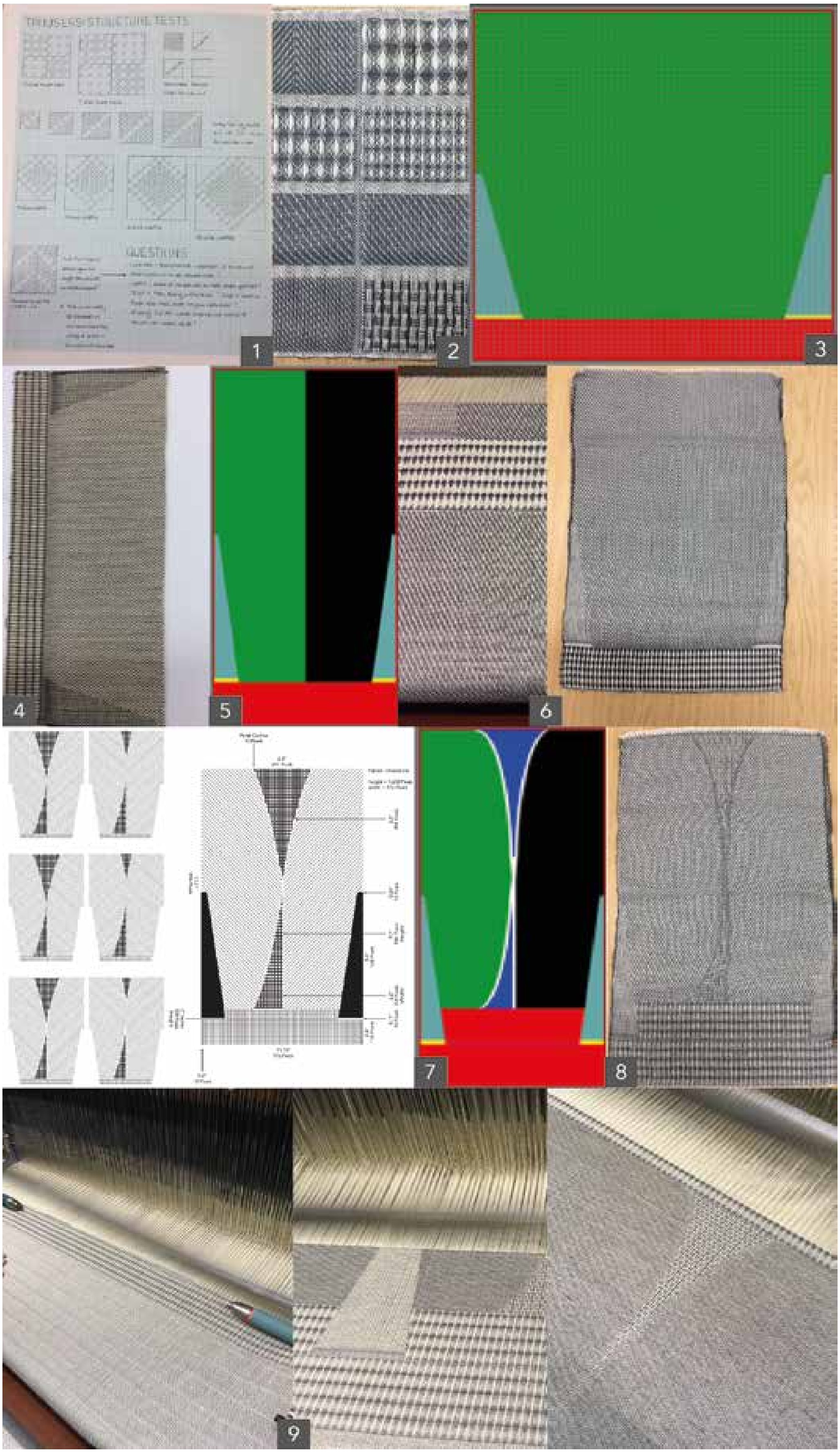


Figure 7.19: Jacquard Woven Trouser Production Process (2018)
Photographs by Anna Piper

Figure 7.19: Jacquard Woven Trouser Production Process (2018)
(Continued) Photographs by Anna Piper

to suit the tolerances of the power loom[5] and to improve the density and durability of the fabric, and additional design features (such as side ventilation panels and gathered cuffs at the ankle) were introduced.

As such, trouser production became a problem-solving exercise, where unforeseen issues were raised and rectified, techniques were developed (and eliminated), and processes were established. These processes (along with the knowledge and experienced gained) were then applied in the development of subsequent designs,

[5] If weave structures with significantly different densities are combined the cloth builds up at different rates during weaving, leading to a differential in warp tension across the width of the loom. This is can result in warp threads breaking and snapping, and the power loom stopping.

making the design and construction of future garments (Dress, Top and Coat) more efficient and focussed.

7.5.3 Application of Sustainability Principles

The trousers used the Planned Chaos approach to pattern development, adapting a conventional trouser block to create seven interlocking geometric pattern pieces that tessellate to form a rectangular lay-plan. This was achieved by using the trouser leg as a “fixed area” (McQuillan 2011: 93), simplifying the individual components, adjusting their dimensions and eradicating curves to eliminate cutting waste. The basic lay-plan was then adapted to suit the mode of production.

The Jacquard trousers were produced using a combination of single and double cloth construction, allowing the two leg panels to be woven simultaneously, and for two of the gusset panels to be connected during weaving rather being stitched/seamed off the loom. However, the use of double cloth construction negatively affected the durability and functionality of the trousers (Section 7.5.4). Utilising the loom’s single-end control and cotton warp, waffle weave structures were applied to integrally shape the trousers’ waistband and the cuffs. Consequently, they are composed entirely of cotton. This mono-materiality means that the trousers are recyclable and biodegradable.

The hand woven trousers are constructed in a single layer, with the two trouser legs and adjacent gusset panels woven consecutively, reducing the number of seams required in the gusset from two to one (Figure 7.20). The required shaping (shrinking) of the waistband is achieved using shrink polyester. Polyester was also used in the warp and the weft to produce a single fibre garment suitable for end of life recycling.

Even though cutting waste was successfully eliminated from the make-up phase of garment construction, the production of the trousers was not waste-free. The hand woven trousers were abandoned before completion, so a significant amount of (unintended) waste was generated. When using the Jacquard loom, the adjustment of the loom’s pick rate (Section 7.5.2) to achieve the correct weft density for the design, required the loom to be in motion, thus producing fabric waste. Whilst this process and production waste was necessary in this research (due to the inaccuracy of the Jacquard power loom’s pick rate regulator), this should not be the case when working with a different (more accurate) power loom.

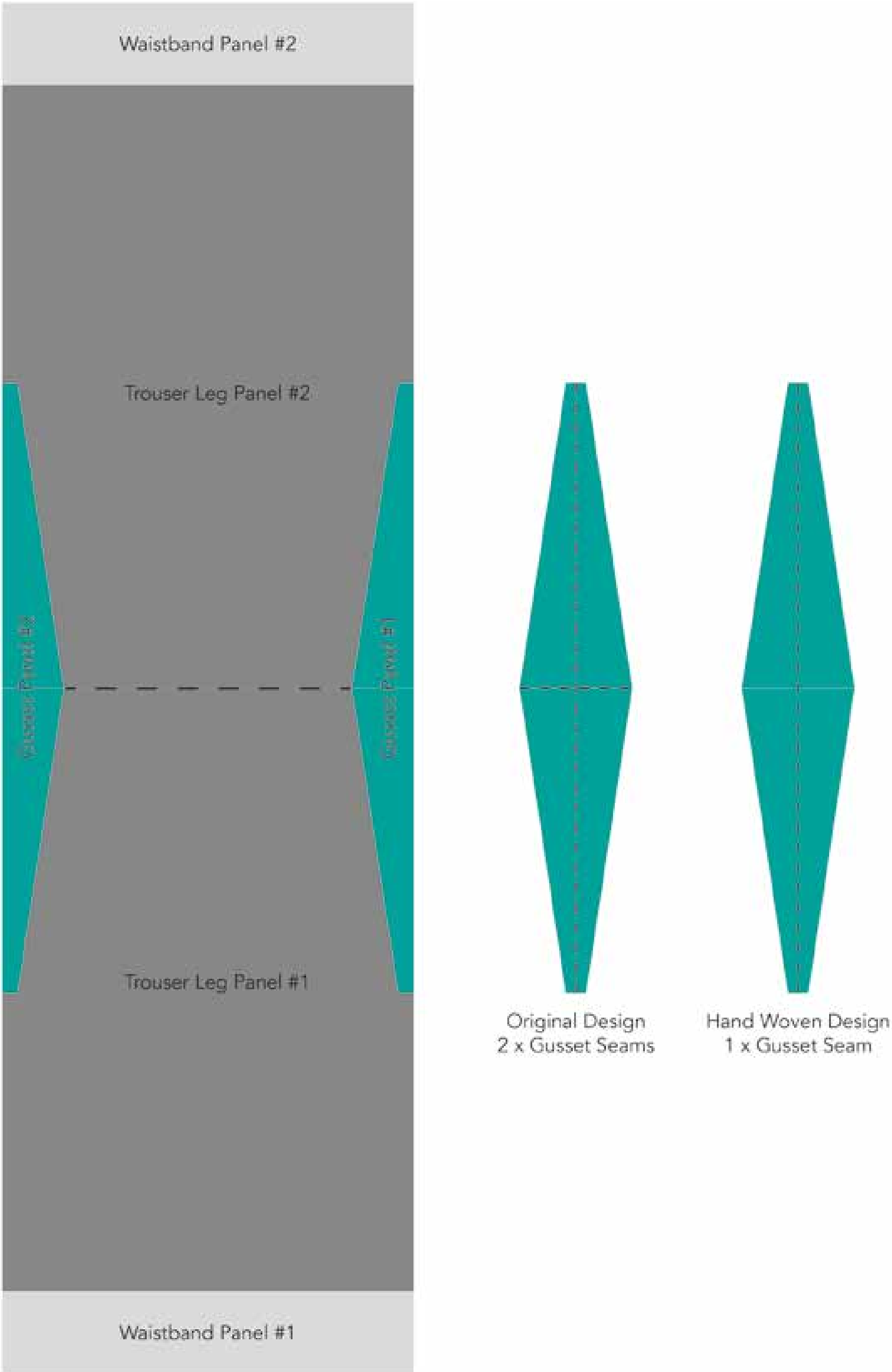


Figure 7.20: Gusset Seams (2017)
Illustration by Anna Piper

7.5.4 Application of Functional Design Principles

Each version of the trousers achieved different levels of functionality based on their mode of construction. Whilst neither design was entirely successful, they both exhibited potential to be developed in subsequent garments.

As the hand woven garment remains incomplete and the Jacquard woven trousers were produced at half-scale it was not possible to assess the effectiveness of their fit or comfort during wear. It was, however, possible to evaluate the handle, weight, durability and functionality of the fabrics produced.

In the hand woven trousers, the plain weave structure combined with the polyester used in double thickness (using two strands together) in the warp and weft, created a dense, soft flexible fabric with a smooth surface and excellent drape – characteristics that are desirable for enhancing mobility in clothing (Watkins & Dunne 2015). The fabric is both light and compact, making it malleable and easy to work with, giving clean lines with little fraying when cut and stitched. The plain weave structure and polyester fibre were also selected, in part, for their abrasion resistance, resilience (Ibid) and structural firmness and stability (Wilson 2001; Corbman 1983).

The Jacquard woven trousers consist of multiple weave structures including satin, twill, huck lace and waffle weaves, all of which provide different visual as well as functional characteristics. It is, however, the use of double cloth construction that has the most significant impact on the fabric functionality and durability. The 30/2ne cotton warp on the Jacquard loom offers a density of 96 ends per inch when working in single cloth but only 48 ends per inch in double cloth. The loom's predetermined tolerances allow for an approximate fabric density of up to 100 ends per inch (depending on the thickness of weft yarn being used and the structure combinations). As the trouser design includes both double and single cloth construction, the density of the fabric in the single cloth sections was compromised, resulting in sections of the trouser pattern being open and unstable. This lack of stability makes the cutting and stitching of the garment difficult, with the fabric distorting under the presser foot of the sewing machine and fraying excessively throughout the garment make-up process. The addition of a seam allowance in a denser structure such as a plain weave would have been advantageous to help to guard against fraying.

Notably, even though the trousers were produced at half-scale it was not possible to reduce the scale of the weave structures to reflect the true relationship between the fabric and garment, as the loom would not tolerate the use of tighter weave structures (Journal Excerpt 7.5). Changing the scale of the weave structure alters its physical properties, behaviour and visual characteristics (including the amount of contraction and stretch in the waffle structure). The impact of this was most evident in the integral shaping of the waistband and ankle cuff, where only a very limited and insufficient amount of shrink and stretch was achieved.

In light of the findings above, the following decisions were made:

- To only produce full-scale garments from this point.
- To focus on garments of single cloth construction.

Although the application of colour coding in the warp for the hand woven trousers (to direct panel shaping) was not deemed to be successful when used in combination with clasped weft weaving techniques (Section 7.5.1), colour and weave structure coding continued to be developed in the garments that followed; albeit in a much simpler form (for example, in simple stripes of solid colour used to denote folds, seams and cut-lines in the t-shirt design (Section 7.6.1)).

7.5.5 Garment Design and Process Potential

Whilst neither trouser design was entirely successful, the design and production processes were hugely informative and were the foundation for process development and subsequent designs. The hand woven trousers' construction was prohibitively complex, with little gained (functionally, aesthetically or sustainably) by constructing the garment in this way. It was, however, the catalyst for the use of 'coding' to guide garment make-up. Despite the issues experienced when working with the polyester (Journal Excerpts 7.1, 7.2 and 7.3), the same type of yarn, sett (warp density) and weave structures were used to construct the hand woven jacket (Section 7.8) due to the handle, weight and visual qualities they produced.

The design and production of the Jacquard woven trousers, with its incremental development (multiple production runs) and identification of loom inaccuracy (pick rate calibration) was invaluable in the establishment of digitisation and production processes both for the Jacquard power loom and the TC2. Additionally, weave structures tested as part of this process were used in successive designs, and the knowledge and experience of working with and combining double and single cloth construction informed the development and direction of the garments that followed.

Whilst not successful in their own right, due to the issues with fabric density, durability and their half-scale format, the Jacquard trousers highlighted the potential of CPW when used in conjunction with looms with single-end control. They demonstrated that complex lay-plans and garment construction, including integral shaping and contoured panelling, can be achieved. This design provided a platform for development, from which the dress, top and coat evolved.

7.6 Garment #2: T-shirt

The t-shirt was the simplest garment produced and the first to be fully completed. The garment was produced on the hand loom and does not contain any integral fabric shaping, instead the design focuses on single-piece and minimal cutting and stitching. It capitalises on the ability to design the warp specifically for the garment when working on the hand loom, rather than being restricted to predetermined warp yarn, colour, width and density as is the case with the digital and hybrid looms. The design of the t-shirt inspired the use and development of functional colour coding within the textile to mark cut lines, seams and folds to direct construction of the garment.

7.6.1 Design and Production Process: Hand Weaving

The t-shirt was designed for and produced on the George Wood Dobby loom. The design was inspired by a simple infant's shirt found in Burnham (1973: 20 – Figure 14), and by the proportions and geometry of the traditional kimono. Working from the basic body, sleeve and length measurements taken from an existing t-shirt, measurements were adapted to fit within a rectangular lay-plan (or piece of cloth).

Producing the garment in a single piece and without generating cutting waste, resulted in some design compromises, particularly in relation to sleeve length. In a similar way to the cut-line of a pattern piece determining the cut-line of the adjacent pattern piece in a Jigsaw zero-waste pattern design (McQuillan 2011: 93), in single-piece garment construction (and ZWPC) the dimensions of a particular part of the garment (in this case

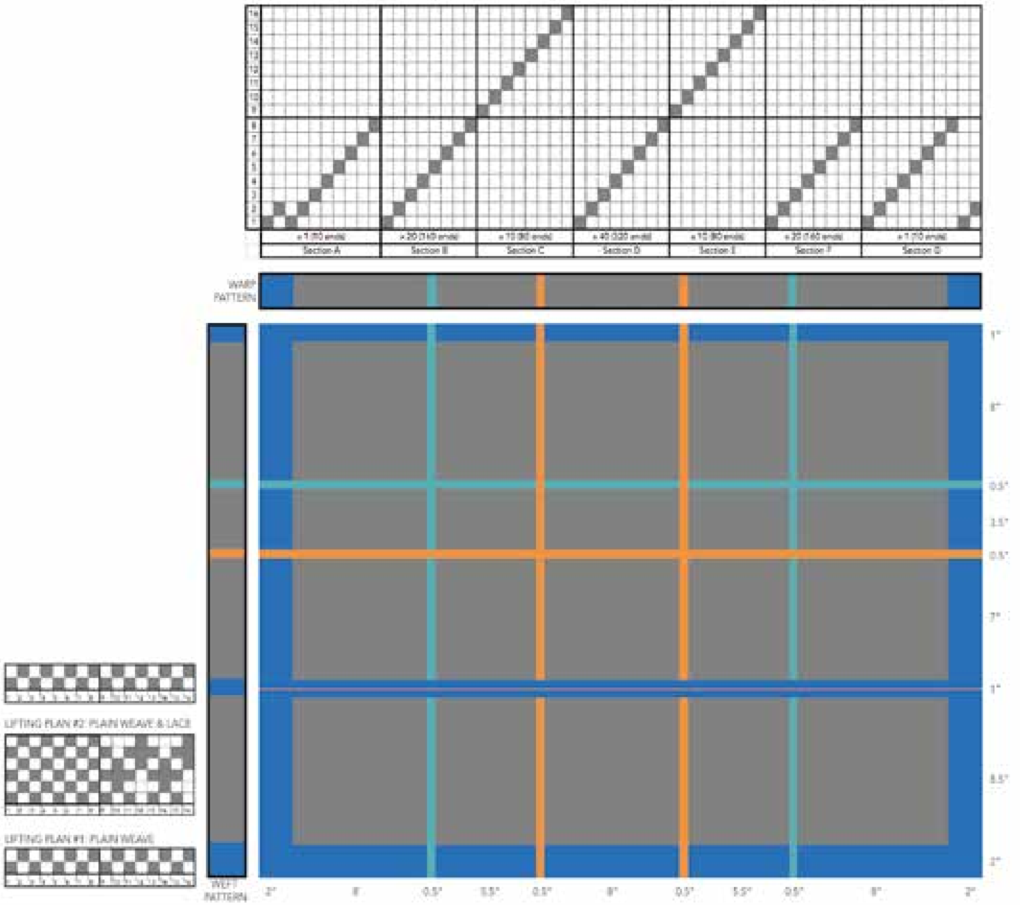


Figure 7.21: Warp Design, Threading and Garment Construction Plan (2018)
Illustration by Anna Piper

the back panel) determines the dimensions of the adjacent part (sleeve length). As such, the sleeves of the t-shirt sit below rather than above the elbow.

Once the garment dimensions and lay-plan were confirmed, following the production of toiles, the warp was designed. The warp design includes threading and colour placement, with colours allocated and positioned within the fabric to indicate cut-lines, folds and seams (Figure 7.21). The following colour coding was applied in this design:

Cut-line
Fold
Seam/hem

On completion of the warp design, the process of warp-making and weaving begins. At this stage the garment design is fixed, and the process of weaving is one of constructing the predetermined design. During weaving, adjustments can be made to the density of

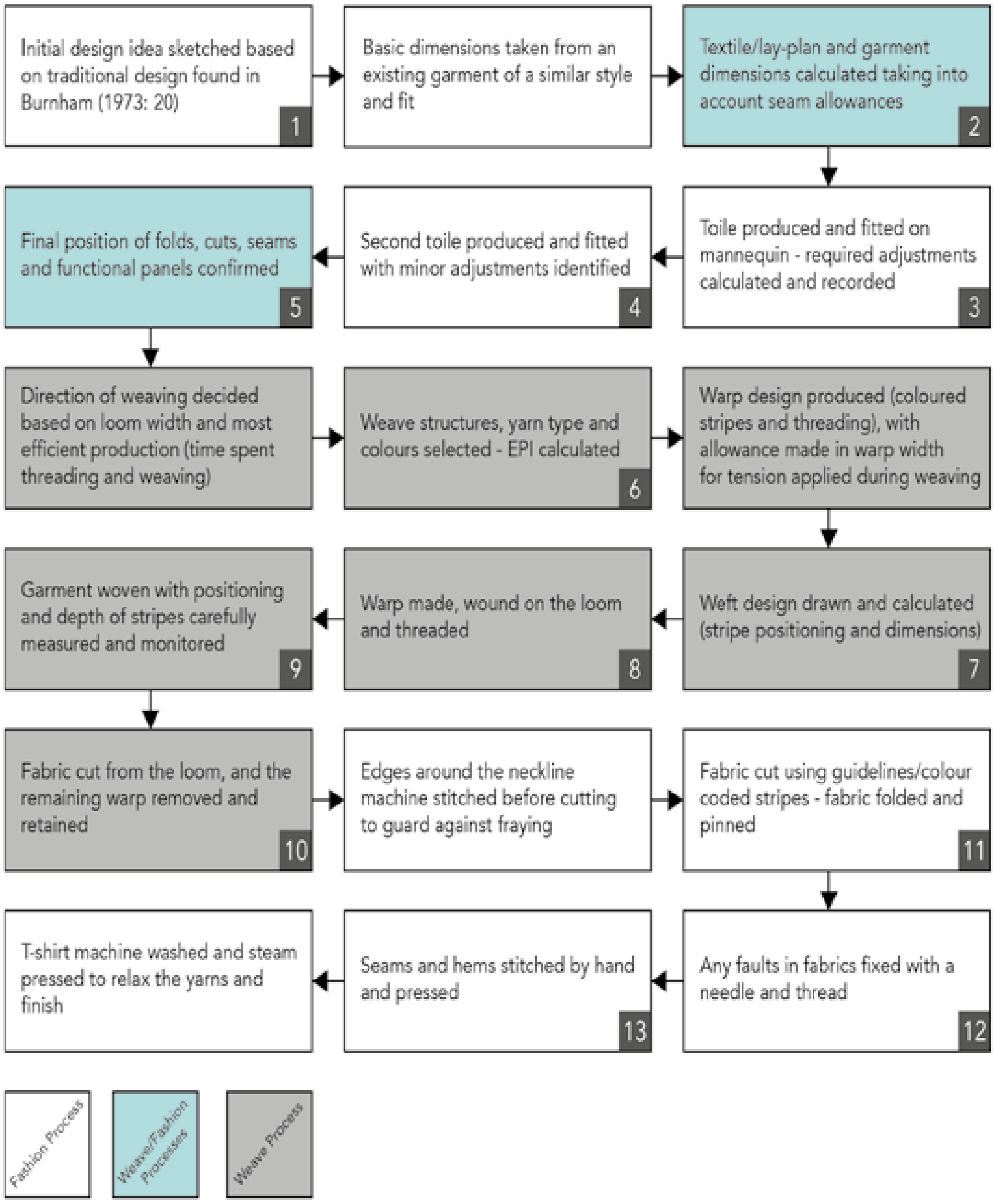


Figure 7.22: Hand Woven T-shirt Production Process (2018)
Illustration by Anna Piper

the cloth and the number of picks being inserted to ensure accurate positioning of the functional stripes. This is something that is far more difficult to manage when working with digitally programmed looms (Section 7.7.1).

The Figures 7.22 and 7.23 provide a visual overview of the design and construction of the t-shirt, from initial design idea to the final garment outcome.


1
Paneling Options
2
41"
3
K+L
4
Front
Pattern Key
Back
5
41"
6
WEFT DESIGN:
COLOUR
7

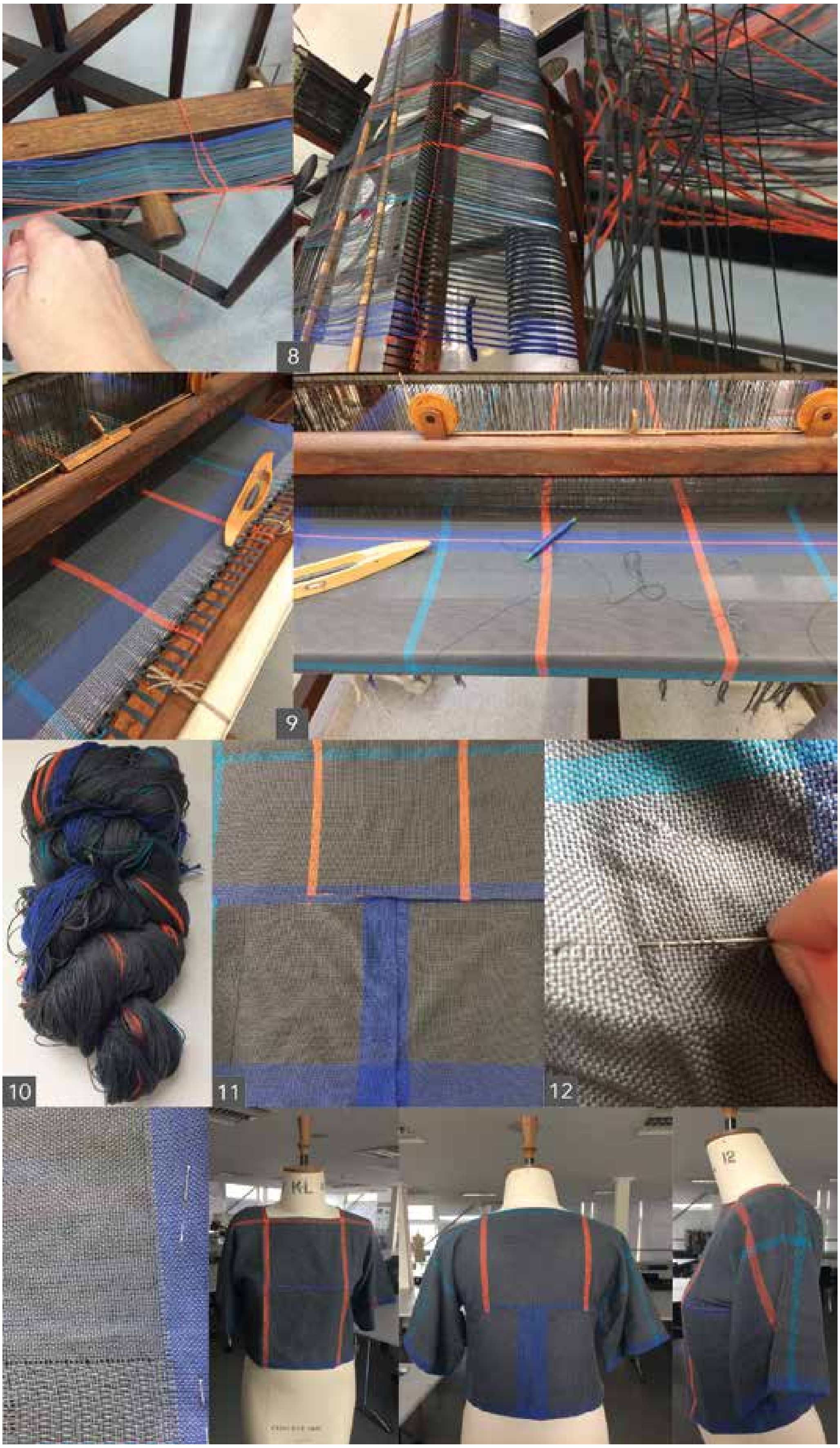


Figure 7.23: Hand Woven T-shirt Production Process (2018)
Photographs by Anna Piper

7.6.2 Application of Sustainability Principles

The t-shirt adopts a simplified Geo Cut approach to pattern design, based on the tessellation of multiple rectangular garment components within a single piece of cloth. Rather than cutting each rectangular block individually, they are amalgamated into a single piece by removing seams, with the pattern only requiring two cuts to construct the garment. The removal of seams increases the "efficiency of fabric use" (Aakko & Niinimaki 2013: 70) as well as minimising post-loom construction, thereby simplifying the manufacturing process (Carrico & Kim 2014: 62).

During t-shirt production, a significant amount of warp waste was generated (35%), however, it was of a usable length and was fully utilised in the production of the coat (Section 7.10). Two identical t-shirt lay-plans were produced as part of this research. If the process of garment construction was upscaled (i.e. applying CPW to small batch or industrial production), the relative percentage of production waste per garment could be significantly reduced by producing multiple garments on a single warp.

A small amount of the warp waste was used in the make-up of the t-shirt (for stitching seams and hems) and to fix some minor faults in the construction of the fabric. This use of waste in garment make-up, combined with mono-fibre construction of the fabric (using 6/30ne cotton and 2/16ne cotton), makes the garment fully recyclable and biodegradable. The sustainability credentials of the garment design and production could be further enhanced by using organic fibres.

7.6.3 Application of Functional Design Principles

The t-shirt incorporates two weave structures; a durable plain weave structure (WRAP 2017: 13) forms the majority of the garment, and an open lace structure is applied to the seamless side panels. These panels provide ventilation around areas of "concentrated sweating" (Watkins & Dunne 2015: 167), such as the armpits, beneath the bust and sides of the torso. The use of hand woven production restricts this panelling to simple geometric rather than contoured shapes.

The soft drape of the fabric and loose relaxed fit of the garment, particularly around the sleeves and shoulders, permits the wide range of movement required by the multi-plane rotational movement of the shoulder joint (Watkins & Dunne 2015) and facilitates both freedom of movement and air circulation (Ibid).

> This area is particularly critical in terms of clothing fit and movement, as many articles of clothing are suspended from the shoulder, yet the movements required from the shoulders, arms, and hands in our lives are varied and constant.
>
> (Ashdown 2011: 280)

The versatile oversized (kimono inspired) shape and dimensions of the garment (square-cut, loose-fitting sleeves and body) can accommodate some changes in body shape and size, as well as providing comfort for longer-term wear (WRAP 2017). However, the simplicity of the neckline, with its square cut and un-seamed/overstitched finishing is lacking in refinement and robustness. This is partly due to the thickness of the cotton used and relatively loose construction which (despite the use of the stable and durable plain weave structure) is prone to fraying.

The bright coloured stripes (described in Section 7.6.1) have a functional purpose, as colour coded 'instructions' for garment construction. But they also add aesthetic interest by emphasising its construction and geometry to give a clean graphic appearance.

7.6.4 Garment Design and Process Potential

The t-shirt, with its single-piece minimal seam construction is the simplest form of CPW. The design embraces the limitations of hand woven construction; producing a basic garment with geometric cut that eliminates cutting waste. This developmental garment, with its functional colour coding and the principles of construction (lay-plan format), provided the model for subsequent designs (the dress, jacket and coat). Using the basic lay-plan as a starting point for the dress and coat design helped to improve the efficiency of the design process. Issues encountered with fabric durability and neckline design (Section 7.6.3) informed yarn choices and fabric density/weight when developing the jacket produced as part of my MMAQ residency (Section 7.8) and the coat (Section 7.10).

In this study the warp was designed to produce one specific t-shirt design. However, there is scope to produce garments of varying lengths, styles and colours using this particular warp. Although not produced as part of this research, a variation on this t-shirt design was considered (Figure 7.24), illustrating how the TC2 can facilitate the production of a garment of greater complexity and functionality – including options

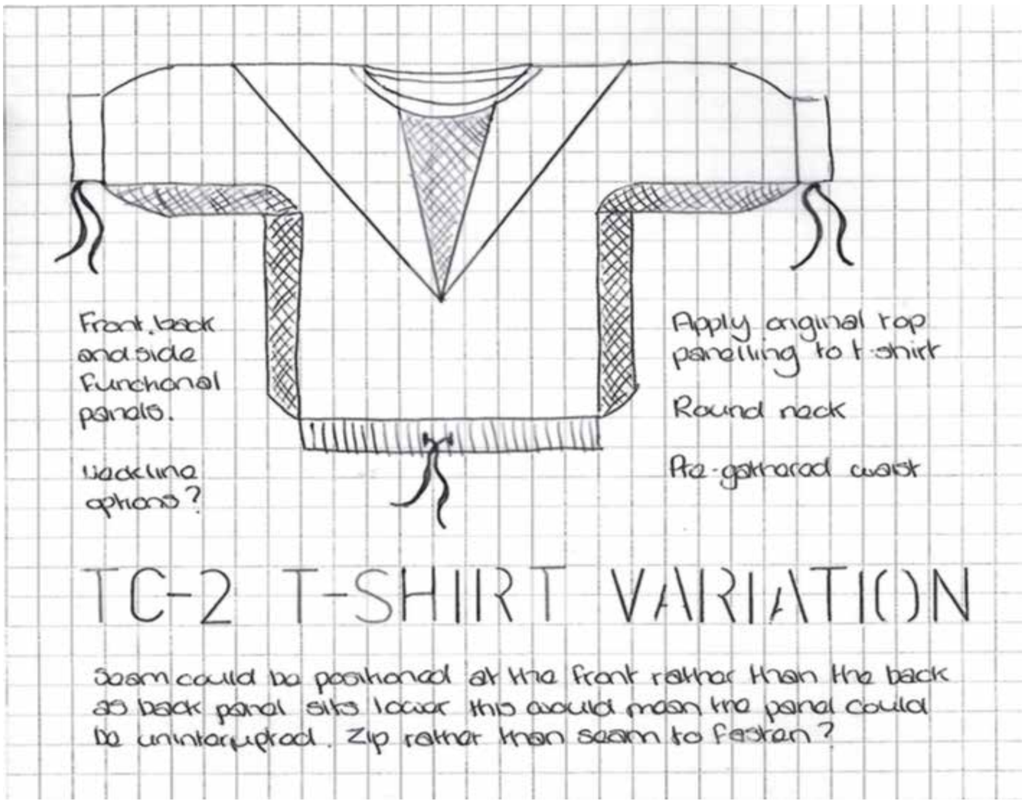


Figure 7.24: T-shirt Design Variation for the TC2 (2018)
Illustration by Anna Piper

for application of further functional thermoregulating panels, use of drawstrings on the sleeves and at the hem for adjustable fit, and a more refined curved neckline shaping. This is an example of the responsive and iterative approach to design that the Transitional Design Methodology aims to stimulate, as well as highlighting the design potential of the CPW system.

This particular design and experience stimulated a return to the original principles of the Transitional Design Methodology[6] (Section 3.3) – to capitalise upon the advantages of hand weaving and to exploit the relative simplicity of hand woven garment construction, resulting in the design and production of a more successful hand woven garment later in the research (Section 7.8).

---

[6] Although the first to be woven, the trousers were not the first to be designed. The design of the top and initial ideas for the t-shirt, dress and coat were being developed alongside the trouser design and production (see Figure 7.14 in Section 7.4).

7.7 Garment #3: Dress

Based on the two-cut, two-seam t-shirt design, the dress was developed in parallel with the t-shirt. The garment was designed for and produced on the digital Jacquard power loom to take advantage of the panelling and shaping opportunities offered by its single-end control. Whilst the dress incorporates a rounded neckline and integral shaping (in the form of tapering stretch panels), the loom's triple-harness/ triple repeat presented significant challenges for the production of a single full-scale garment. This, along with the restrictions the loom places on both garment sizing and styling due to its predetermined warp width, meant that the dress was the only full-scale garment produced using the Jacquard power loom. However, the design and digital programming processes established during the development of the dress were invaluable when working with the TC2 to produce the top (Section 7.9) and coat (Section 7.10).

7.7.1 Design and Production Process: Digital Weaving

Figures 7.25 and 7.26 capture the design and production process employed in the development of the dress. In contrast to the t-shirt, where the desired garment dimensions were the starting point for design, the dress design began with the width of the warp – in the same way that the zero waste fashion designer works with (or within) the fabric width (Rissanen & McQuillan 2016: 124). This resulted in a size 6 prototype, whilst the other garments produced use size 10 dimensions. The enforced repeat across the width of the warp posed the greatest design challenge, as any panelling and design features automatically repeat a minimum of three times in the garment.

Working within the maximum warp width of 36.7 inches (which includes a 0.5 inch selvedge at either side of the cloth) and the width of the horizontal repeat (11.9 inches), the ideal outline of the pattern/garment was plotted, followed by the essential design features (neckline, sleeve panels and seam allowances). These features were then duplicated across the design to create the pattern repeat. This resulted in the neckline shape being repeated and forming an incidental and unavoidable 'decorative' patch on either shoulder.

The principal aim for this garment was to incorporate integral shaping, using the shrink and stretch capabilities of the waffle weave structure (Section 7.3.2) to draw the dress in at the waist and hem, and to gradually taper the skirt to create a 'tulip' style. This was

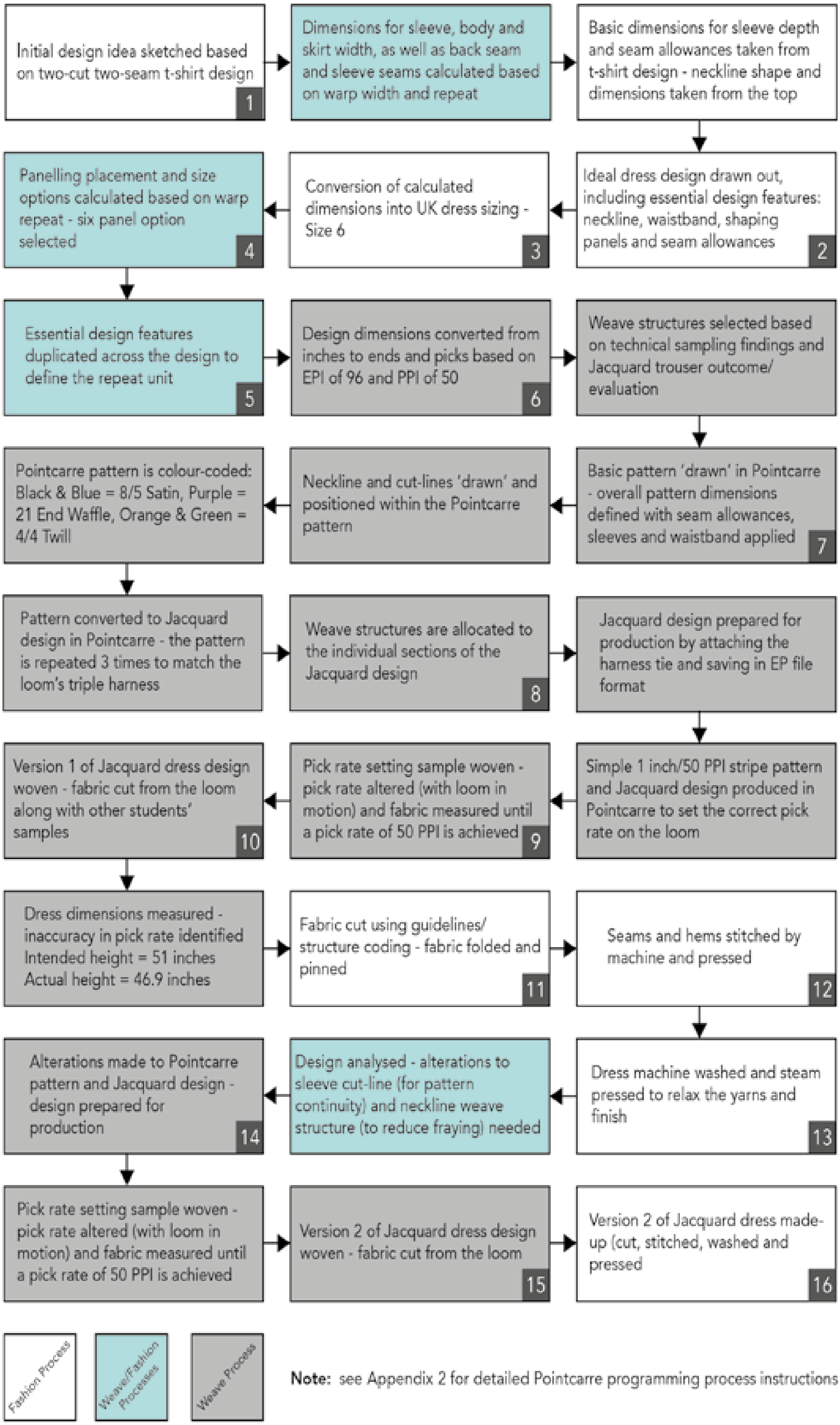


Figure 7.25: Jacquard Woven Dress Production Process (2018)
Illustration by Anna Piper

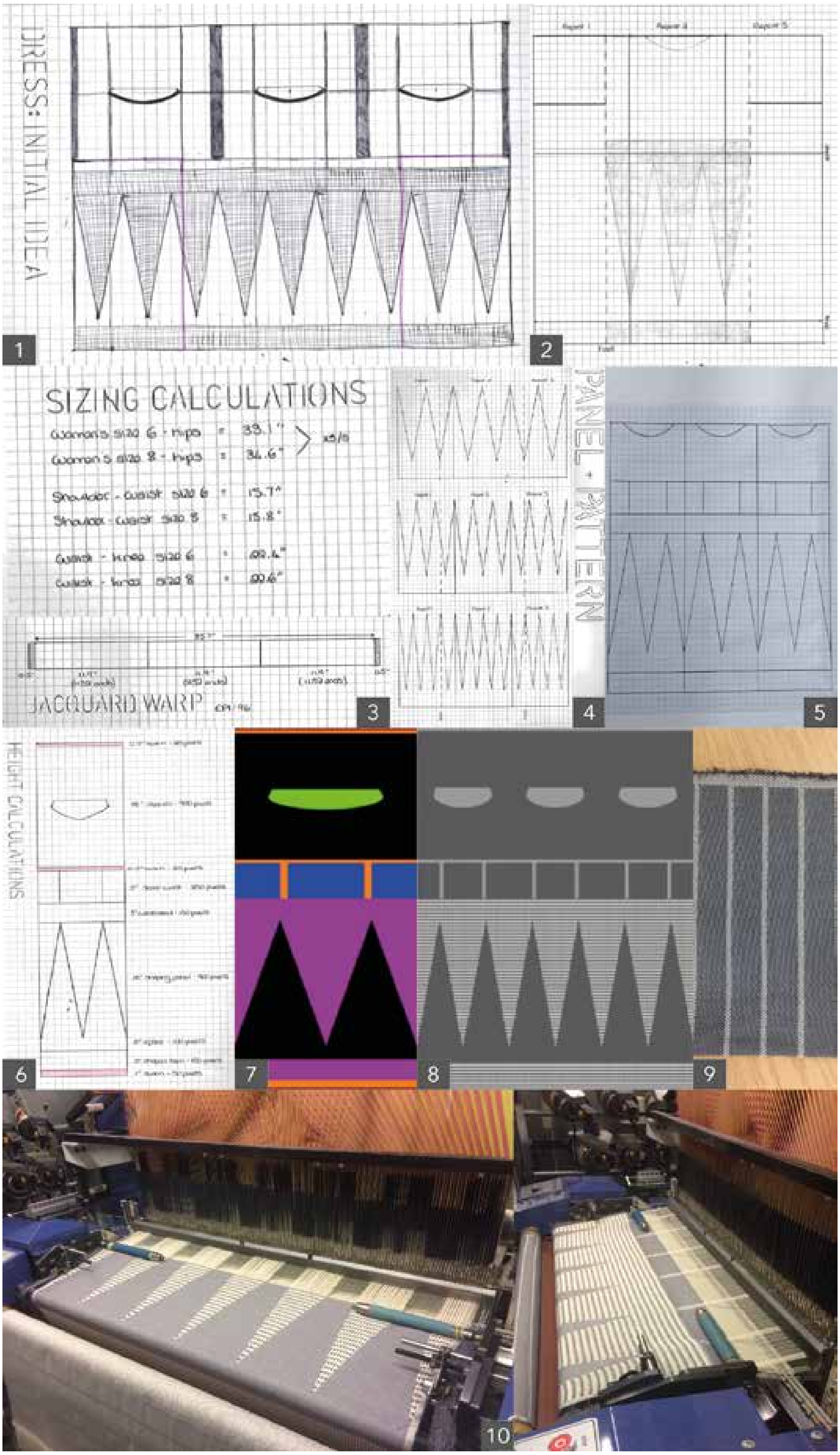


Figure 7.26: Jacquard Woven Dress Production Process (2018)
Photographs by Anna Piper

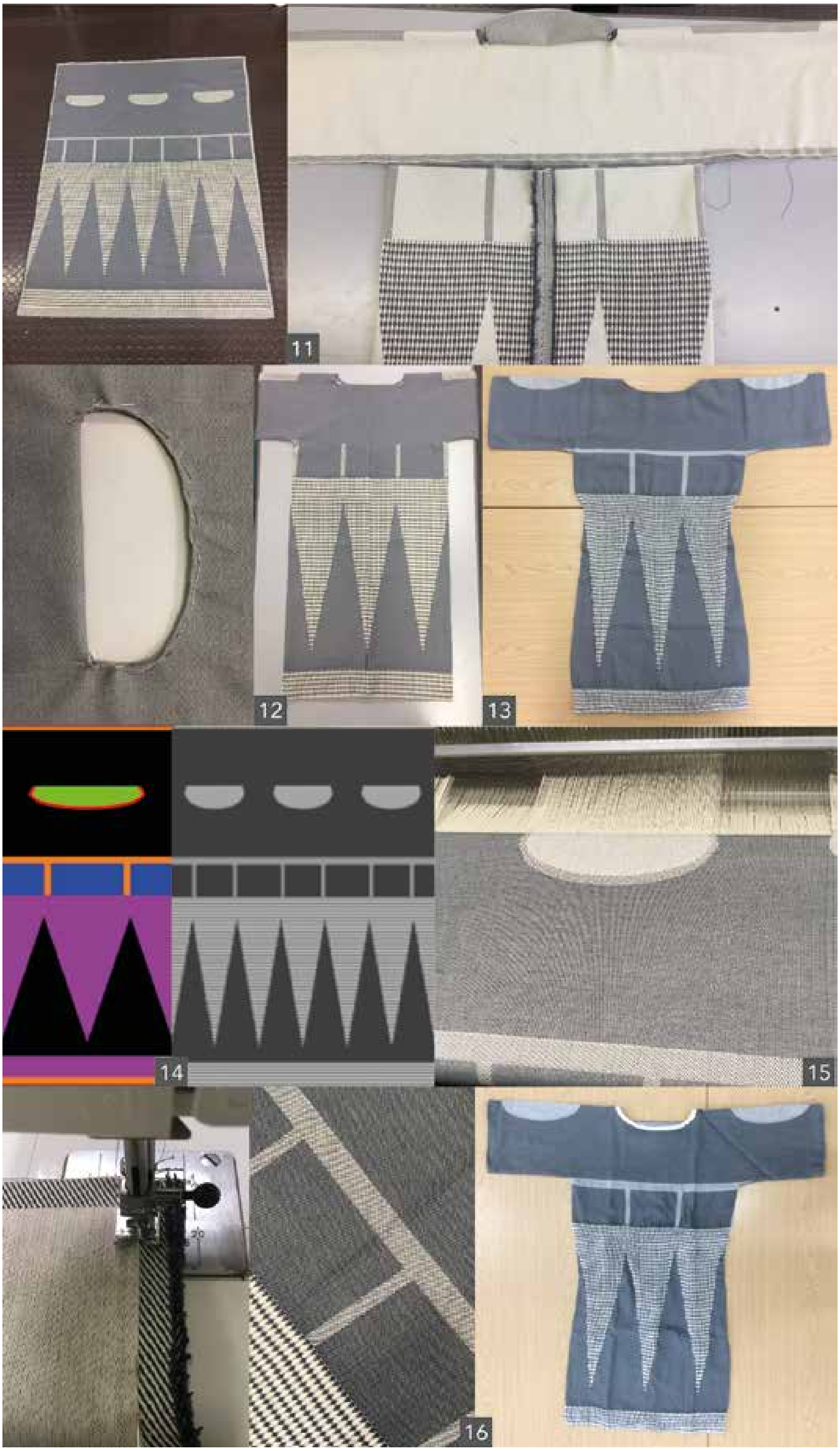


Figure 7.26: Jacquard Woven Dress Production Process (2018)
(Continued) Photographs by Anna Piper

Figure 7.27: Panel Placement and Sizing Experimentation (2018)
Photograph by Anna Piper

to be achieved by applying horizontal bands at the waist and hemline and positioning a series of triangular tapering panels within the skirt. The idea for the panelling was based on the principle that the cellular construction of the waffle structure (when washed) contracts, as the width of the panel containing the structure narrows, the level of contraction reduces. As this functional panelling was a dominant (visible) design feature of the dress, the positioning, visual balance and impact was integral to the garment's aesthetic success. A series of panel placement and sizing options were considered and visualised on the body (Figure 7.27 and Sketchbook Annotation 7.2). Again, this was governed by the pattern repeat, and involved a number of calculations to determine dimension possibilities, number of panels and how they could repeat.

It is important to note that it was not possible to imitate this contraction in a toile to test the dress design before weaving – the design was therefore based on existing experience and knowledge gained during the Component Construction phase of the research (Journal Excerpt 7.6). As such, the process involved a level of "calculated risk and uncertainty" (McQuillan 2011: 85), with a substantial amount of work and effort required for the development, digitisation and weaving of the design before its success can be assessed.

Figure 7.28: Jacquard Power Loom: Cutting Away of False Selvedge (2018)
Photograph by Anna Piper

Weave structure coding, rather than colour coding, was used to guide garment make-up to accommodate the Jacquard power loom's existing warp. A 4/4 twill structure was used to indicate cut, seam and fold lines. The twill was positioned next to structures with very different visual qualities (such as 8/5 satin and 21-end waffle) to give them definition. However, the use of structure coding did not have the same visual clarity as colour coding, largely due to the triple repeat which resulted in cut and fold lines appearing in sections of the garment where they were not needed.

A loom with a single-harness (repeat) would allow many of the challenges and issues experienced during the dress design process to be overcome (Section 7.7.4).

7.7.2 Application of Sustainability Principles

Like the t-shirt, the dress utilises a single-piece, minimal seam approach to eliminate cutting waste and minimise post-weaving construction. As with the Jacquard woven trousers (Section 7.5.3), although cutting waste is eliminated from the garment's make-up, a small amount of fabric waste is generated when adjusting the loom's pick rate to suit the dress design.

Furthermore, whilst the garment was designed to accommodate the selvedge as part of the back and sleeve seam allowances, industrial looms (such as the Jacquard power loom) have a blade positioned at either side of the loom to cut away the "false selvedge" (the loose threads that build up at the edge of the cloth (Figure 7.28)) (Brown & McQuaid 2016:52) creating a small amount of waste[7].

The generation of warp waste, the most significant source of waste when hand weaving (Section 5.5.1), is minimised when working with the industrial Jacquard power loom, as a single warp can be used for several production runs. In a university setting the garment is woven on a standardised warp, cut off the loom (as part of a batch of sample fabrics) and the warp remains in use. If produced in an industrial context, multiple garments could be woven on a single warp.

By capitalising on the inherent stretch and contraction of the cellular waffle weave structure, rather than using an 'active' yarn (such as Lycra or high twist wool) in the functional panels, integral shaping was achieved without compromising the dress's mono-materiality. The dress was composed entirely of 30/2ne combed cotton, making it fully recyclable and biodegradable. The combination of ecru warp and dark grey weft creates a versatile tonal grey palette, paired with a simple cut (intended) for long lasting seasonless appeal (WRAP 2017).

7.7.3 Application of Functional Design Principles

The dress is composed of a number of weave structures selected for durability, functionality and aesthetic appearance. The density of the warp combined with the satin and twill weave structure results in a smooth surfaced, compact, flexible and abrasion resistant cloth (Thomas 2009), whilst the tight twill structures used in the neckline facing and hem provides a clean cut-line and greater fray resistance than the satin structure. The waffle structure, selected for its shaping and stretch capabilities, is the loosest and therefore least durable structure but this is outweighed by its ability to integrally shape the garment; subtly gathering and tapering the silhouette, while offering stretch and providing ease to aid mobility and comfort (Watkins & Dunne 2015).

---

[7] In a modern textile mill, 4 percent of the weft thread is wasted." (Brown & McQuaid 2016: 52). This production waste is often invisible to the fashion designer (Ibid: 54) and represents waste that is associated with garment design and production that is disposed of earlier in the supply chain.

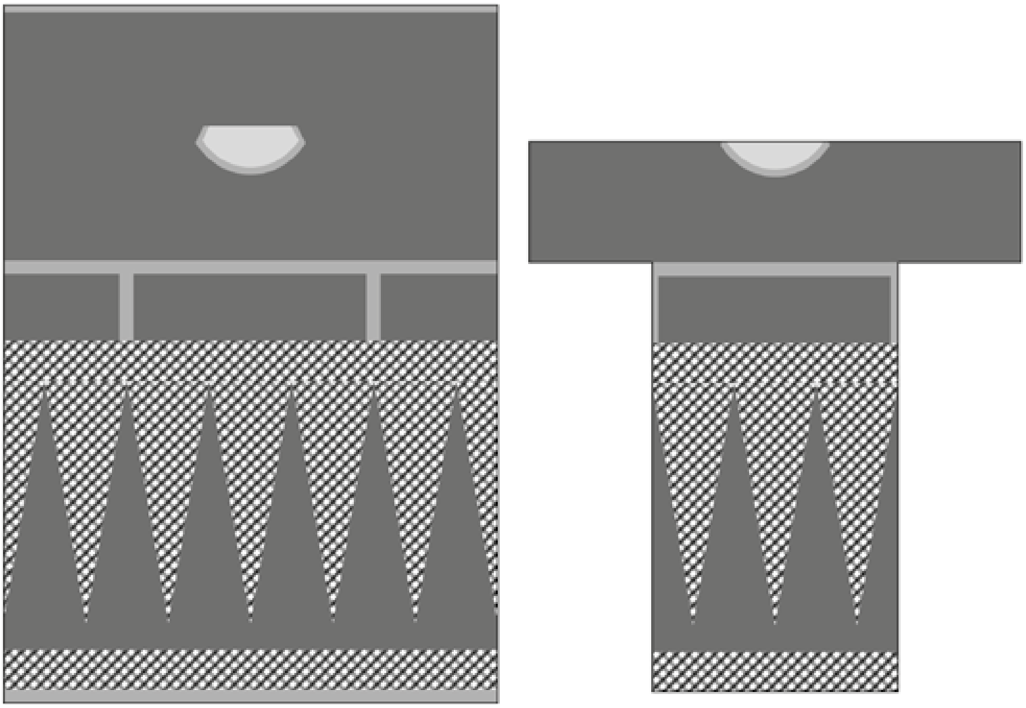


Figure 7.29: Ideal Jacquard Dress Design (2018)
Illustration by Anna Piper

The functional panelling (waffle structure within triangular panels) is visually striking; bringing interest and impact to the otherwise simply styled garment. Additionally, the use of multiple (warp and weft-facing) weave structures provides textural and tonal interest without introducing different yarns and compromising the garment's material sustainability (Section 7.7.2). The triple repeat results in some additional 'decorative' elements, where essential design features such as the neckline and cut/fold lines, appear as incidental patterns. Unfortunately, this reduces the clarity of the structure coding designed to guide the make-up of the garment. Figure 7.29 shows the ideal design and functional patterning, had the Jacquard loom not imposed the horizontal repeat.

The simple two-cut, two-seam construction creates a simple, versatile, geometric silhouette, but the size limitation imposed by the loom's set-up means that the dress is closer fitting (with a less contemporary appearance) than was desired. Had a more oversized silhouette been possible, the garment could be more responsive to the movements and changing needs of the wearer.

7.7.4 Garment Design and Process Potential

The dress prototype advances and refines the techniques and designs used to produce the trousers and t-shirt; introducing integrally shaped engineered panels and applying them to a full-scale garment. Issues relating to fabric density and durability have been resolved by working with single cloth construction and a warp with a higher ends per inch/thread density. The use of the Jacquard power loom has imposed a number of restrictions on the dress design that have impacted on the garment's functionality and sizing. By working creatively with these constraints, the challenges presented by the loom's predetermined set-up (warp width and triple-harness/repeat) have been overcome, resulting in a viable zero waste dress design, with a strong individual aesthetic style.

The basic dress design could be developed further on a loom with a single repeat (such as the TC2, which was not available for production at this point in the research), this would allow for variation in the design, positioning and scale of panelling and pattern for functional and/or decorative purposes. It would also enable rotation of the lay-plan for the dress to be woven from side to side rather from than top to bottom, to increase the size (width) of the dress for a relaxed fit and contemporary style – multiple sizes would be possible.

The ability to produce a simple lay-plan with engineered pattern suggests that garments and lay-plans with greater complexity could be produced, to take greater advantage of the Jacquard loom's ability to produced curved shapes and panels. In this study the researcher's limited fashion design experience impacts on the complexity of the lay-plans and garments being produced. There is scope to develop lay-plans with patterns engineered and positioned within individual garment components (for both functional and decorative purposes) to minimise or eliminate pattern matching.

7.8 Garment #4: Jacket – MMAQ Residency

The jacket was produced as part of a standalone project during my residency at La Maison des Metiers d'Art de Quebec (MMAQ) in May and June 2018. The project 'Colour, Cut and Craftsmanship', inspired by the Japanese design principles of quality, functionality, simplicity and craftsmanship, investigated notions of genderlessness in textiles and fashion using traditional 'feminine' textile techniques as visual inspiration (see Appendix 7 for the project proposal). In contrast to the garments produced solely

Figure 7.30: MMAQ Residency Sampling (2018)
Photographs by Anna Piper

for this PhD study, the project explored the creative and aesthetic rather than technical possibilities of designing a textile engineered for a particular garment. Two lengths of fabric for use in kimono style jackets were produced during the residency, the first (less decorative) design is presented in this section.

Figure 7.31: Jacket Warp Designs (2018)
Photograph by Anna Piper

7.8.1 Design and Production Process: Hand Weaving

The process began with the development of a range of fabric samples that experimented with colour, pattern and structure (Figure 7.30), before selecting and combining a number of designs in a single garment. Using the proportions of the t-shirt as a guide, the cropped geometric jacket was developed (without producing a toile) with a range of options being explored to configure the lay-plan (Journal Excerpt 7.7). A primary consideration in this process was efficiency – reducing loom set-up time by designing a narrow warp, to maximise weaving time. Although narrow, the warp design is quite complicated (Figure 7.31); featuring a number of coloured blocks and stripes, with the multiple and different numbers of yarns threaded through the heddles. The warp consisted of decorative stripes, as well as functional stripes to indicate cutting lines and seam allowances. Block threading (with supplementary warp yarns[8]) was used to apply pattern and to facilitate the placement of functional panels.

A Leclerc, 16 shaft, computer controlled dobby loom was used throughout the project. The computer determines the lifting of the shafts based on programmed lifting plans,

[8] Additional warp yarns used purely in the application of pattern. The yarns can be selectively woven or left out of the design as desired.

this replaces the peg and lag system used to control the George Wood and AVL hand looms used elsewhere in the research. The loom is still operated using a treadle to instigate the lifting of the shafts, the weft is inserted by hand and individual lifting plans 'drawn' on the computer and selected when needed. The full design is not programmed and predetermined, as it is when working with the Jacquard power loom or TC2 hybrid loom.

Woven over a four-day period, as part of the residency, the jacket was made-up on my return to the UK. The weaving and garment make-up processes were captured using photography and film, and are illustrated in Figures 7.32 and 7.33.

7.8.2 Application of Sustainability Principles

Abiding by the sustainability principles developed for this PhD study, the garment is constructed from a single fibre - polyester - and uses a zero waste lay-plan. Applying the techniques developed during my MA research, warp and weft threads are grouped to create strong visual effects, and to add depth and relief to the textiles, without introducing different fibres.

Measures were put in place to manage warp waste. Waste produced during experimental sampling integrated in the weft when constructing the jacket. However, it was not feasible for me to return to the UK with the warp waste generated during garment production to use in subsequent designs. Warp waste was therefore minimised by weaving as much of the warp as possible.

7.8.3 Application of Functional Design Principles

This jacket, in contrast to the other garments produced, includes decorative patterning without a specific function. The weave structures and fabric density were applied to create a durable, stable and softly draping fabric to suit the loose unstructured nature of the simple geometric garment silhouette. The composition, construction and handle of the hand woven trouser pattern, influenced my choice of yarns, warp density and weave structures. The functional open panelling under the arm and down the sides of the jacket, mirrors the panelling in the t-shirt design.

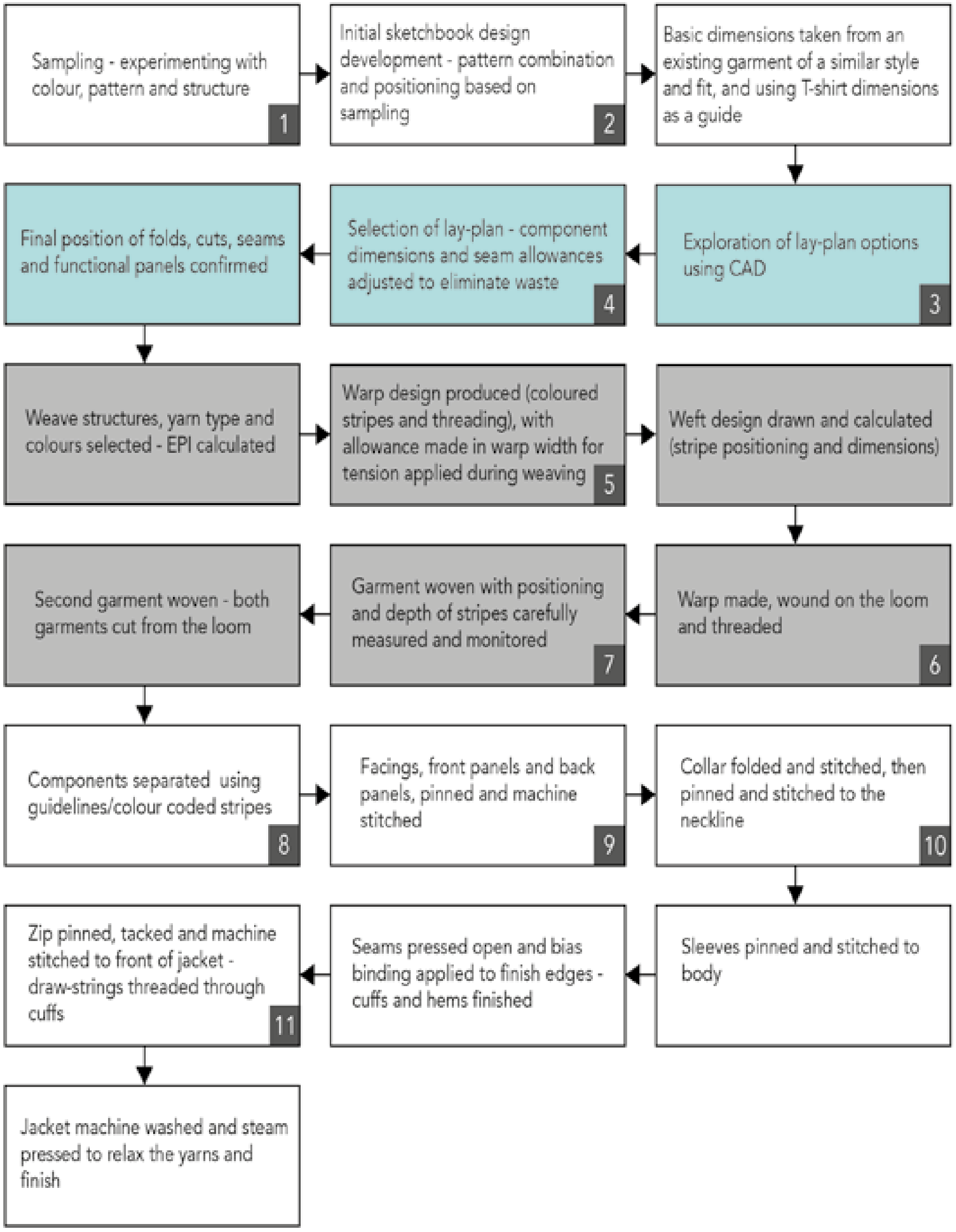


Figure 7.32: Hand Woven Jacket Production Process (2018)
Illustration by Anna Piper

The fit and style of the jacket is informed by the simple geometric construction and versatile shape of the Japanese kimono. The style was selected and developed both to adhere to the functionality principle of the PhD research, and for its ability to "neutralize "signs" of gender" by deconstructing the body "taking away the physical manifestations of biological sex" (Scanlan, 2015: 223). Thus, balancing the requirements of the PhD with the creative exploration of the MMAQ residency.

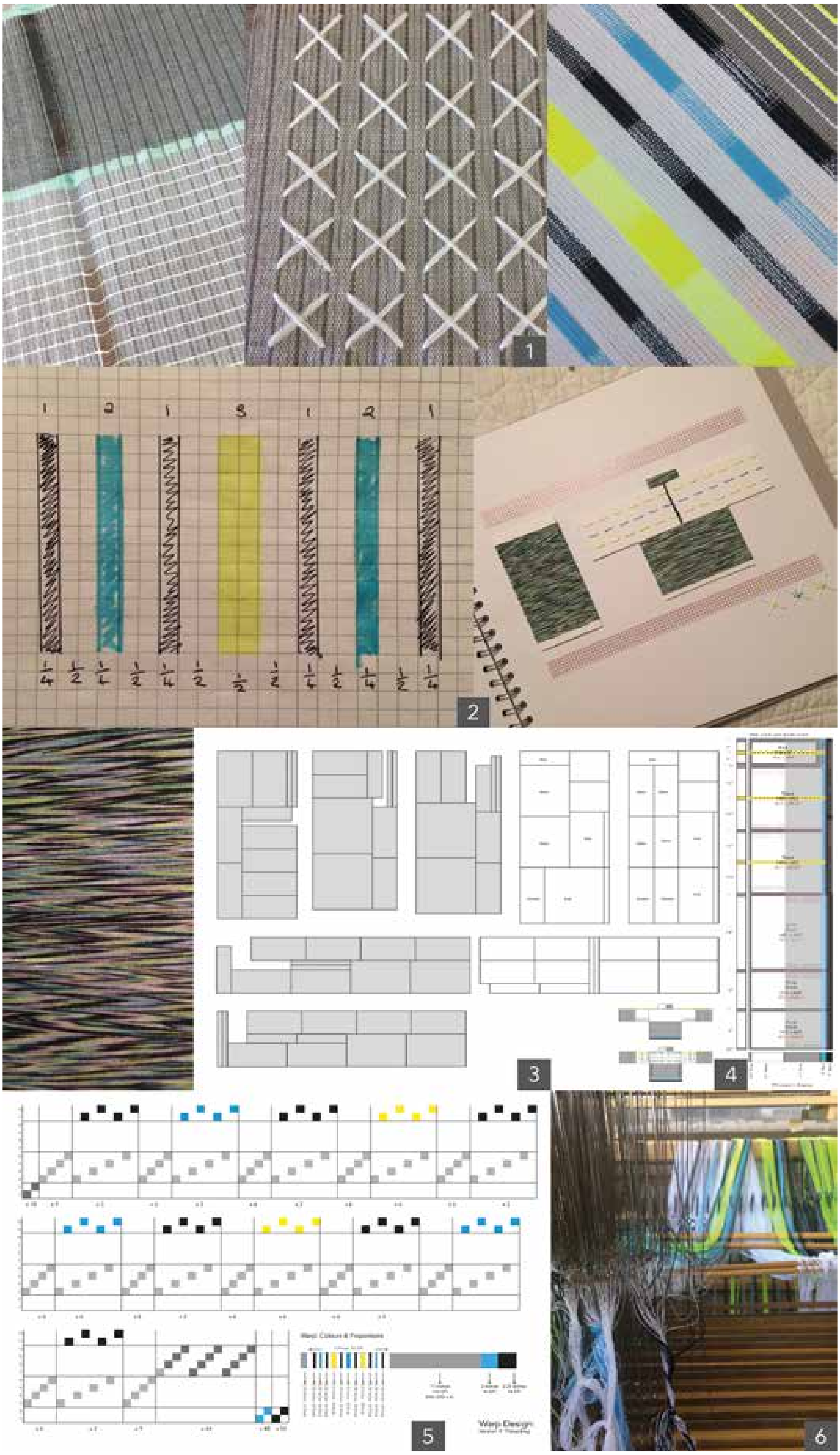

1
2
3
4
5
6

Figure 7.33: Hand Woven Jacket Production Process (2018)
Photographs by Anna Piper

7.8.4 Garment Design and Process Potential

The construction of this garment, along with the dress and t-shirt, influenced the design and construction of the coat. The jacket has a much stronger, vibrant aesthetic than the other garments produced. It brings together the techniques established during my MA studies, with the lay-plan design and colour coding methods developed throughout the PhD. In doing so it showcases the creative possibilities and potential of CPW, as multiple visual qualities and patterns are applied within the lay-plan that visually enhance the shape and construction of the garment. Likewise, it demonstrates how, by working creatively with colour, pattern and yarn thickness, visual interest and impact can be generated without mixing fibres; ensuring mono-materiality for end of life recycling.

The jacket's graphic contemporary aesthetic is in stark contrast to other hand woven fashion garments seen in the bespoke craft market (Section 4.3.1). Although the application of decorative patterns is not an area pursued in this investigation, there is scope for further research in this area. The integration of decorative and repeat patterns with CPW, has the potential to reduce the need for pattern matching and minimise associated cutting waste.

7.9 Garment #5: Top

The original top design was the first to be completed (on paper and in toile form) and the first to be woven on the TC2. However, the design was not woven until the later stages of the research due to the delays in the installation of the TC2 loom[9]. Using a combination of double and single cloth weave structures, the body and sleeves of the top were developed to be produced as a composite (or fully formed) garment (Figure 7.34), with pockets being attached and edge finishing taking place when the garment was removed from the loom. The top is therefore the most complex garment produced as part of the research, both in terms of garment/textile construction and digital programming (Section 7.9.1).

[9] Whilst the TC2 loom was not available for production until November 2017, the warp specification (size, type of yarn and number of thread per inch) was known. As such it was possible to develop a garment design based on these specifications.

Figure 7.34: Top Woven in Composite Garment Form (2018)
Photograph by Anna Piper

The garment adopted the Embedded Jigsaw and Planned Chaos approaches to zero waste fashion design. The pattern was built around the fixed positioning of functional panels on the front and back of the top (rather than around a fixed pattern piece) and the lay-plan consists of two variations of the top design, positioned side-by-side to utilise the full width of the warp (Figure 7.35). Using the body (its kinetic movements, anatomy and sweat patterns) functional panels are strategically positioned to facilitate movement and ventilation, whilst weave structures and yarns are applied to subtly shape the garment.

Being the first garment to be developed, the design process involved the production of multiple patterns and toiles, and different iterations of the design and its construction being explored (Section 7.9.1). The protraction of the design and production process did have some advantages, as the findings from the production of other garments (the top, trousers and dress) were able to influence and shape the final design. The inability to test the design on the loom and reproduce it a second time (due to the aforementioned delays) to adjust the dimensions, impacted on its overall success. However, as the first garment produced using the TC2 loom, both the experience and outcomes informed the development, programming and the weaving of the coat.

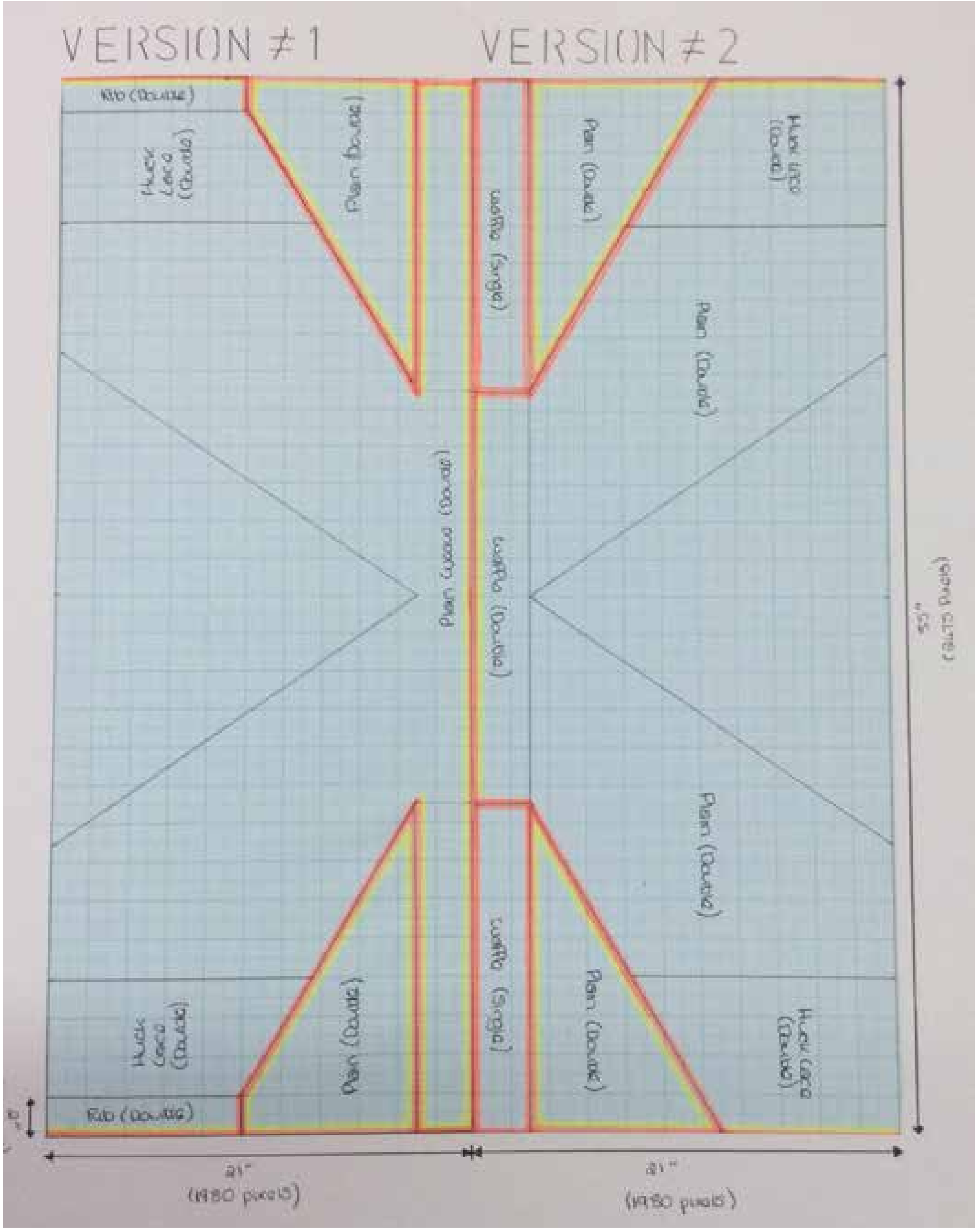


Figure 7.35: Lay-plan with Two Variations of the Top Design (2018)
Photograph by Anna Piper

7.9.1 Design and Production Process: Hybrid Weaving

The design of the top was inspired by and based upon the anatomy of the human form, in particular the multi-planal movements of the shoulders and elbows and the generation of heat during high-intensity activity. A series of functional panels containing waffle weave structures to provide a degree of stretch within the textile, and an open huck lace structure to facilitate airflow were developed. Once the positioning of the functional panels was confirmed the shape of the top was developed. This involved a series of physical and digital patterns and toiles being produced, to experiment with sleeve, waistband, cuff and pocket styles and shapes. Two methods of construction were also considered:

- The construction of two composite garments, woven alongside one another.
- The production of a single garment lay-plan to be folded and stitched together once removed from the loom.

Having chosen the composite garment design, the digitisation process for construction on the TC2 commenced. In contrast to the digitisation of the trousers and the dress, where the lay-plan was drawn directly into the weave software (Pointcarre), the pattern was produced using Adobe Illustrator and then imported into Pointcarre. Due to the complexity of overlaying the components of the top, in particular the neckline and functional front and back panels, to form a 2D single layer pattern to construct a 3D double layered woven garment, I felt that an advanced drawing software was required to produce an accurate pattern[10]. The multi-stage digitisation and production process is illustrated in Figures 7.36, 7.37 and 7.38 (also see Journal Excerpt 7.8).

The initial digitisation of the design took place more than a year before the garments were woven, in the interim period the t-shirt, trousers, dress and jacket were produced. In response, the design was reviewed and a series of adjustments were made (Journal Excerpt 7.9/Sketchbook Annotation 7.3). Despite producing a number of samples to confirm the appropriateness of weave structures and the required weft density, producing a short test strip of fabric on the loom to check the pick rate/density, and measuring the dimensions of the first section of the garment during weaving, the completed garments were significantly smaller (shorter from sleeve edge to sleeve edge) than they should have been. The pick rate achieved in the test strip and sampling was 22.5 (single cloth) and 45 (double cloth), yet in the final garment it was 30 (single cloth) and 60 (double cloth). The cumulative effect of this discrepancy across the whole garment is a massive 13.5 inches. The discrepancy can be attributed to the effects of

---

[10] Adobe Illustrator allows for the creation of multiple layers with different transparencies, which can then be overlaid to both visualise the simultaneous construction of two layers of fabric and to create the different shapes and blocks of colour required to programme and position the weave structures when the design is transferred to Pointcarre. Pointcarre does not offer such an advanced level of drawing and layering of images.

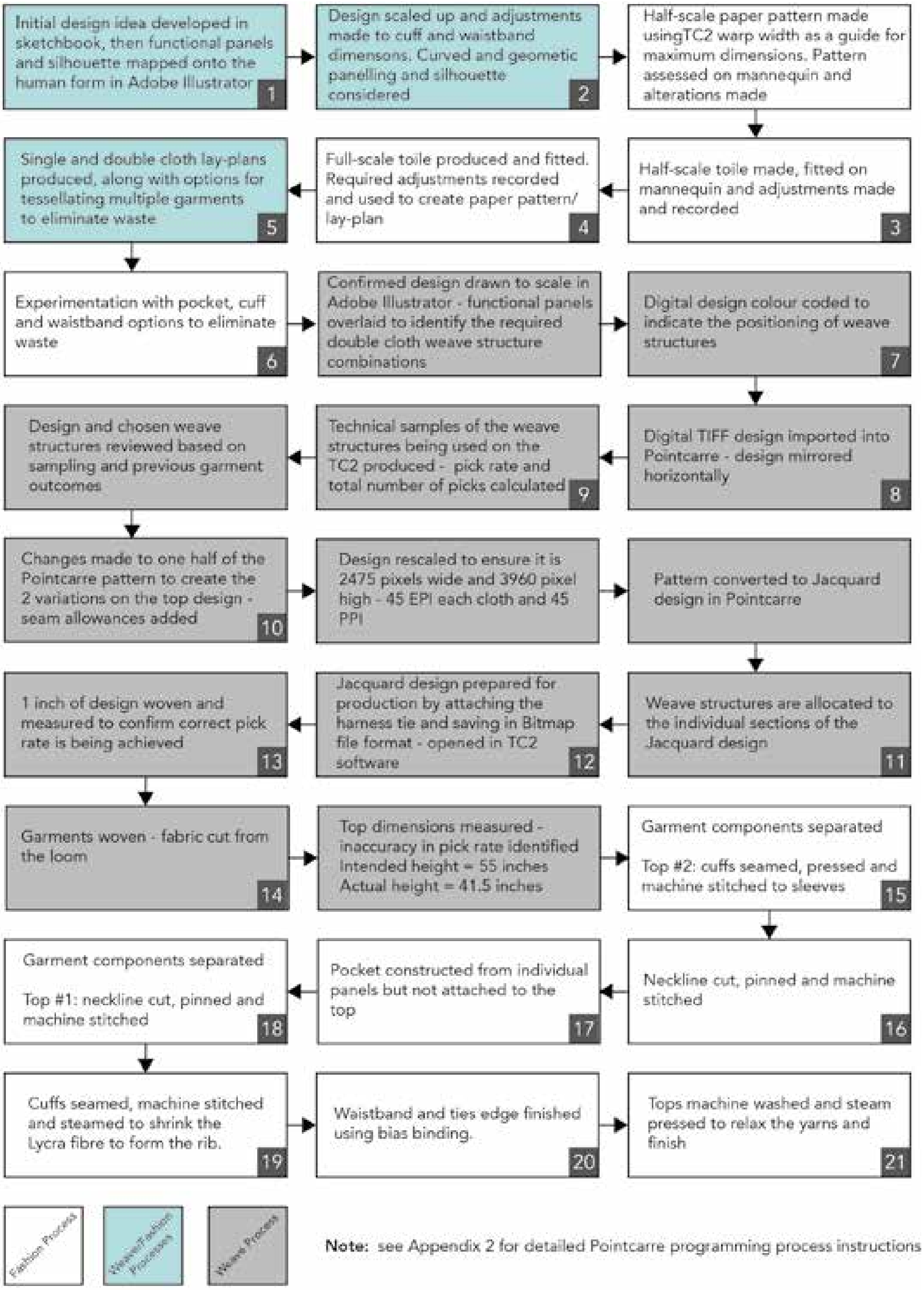


Figure 7.36: Hybrid Top Production Process (2018)
Illustration by Anna Piper

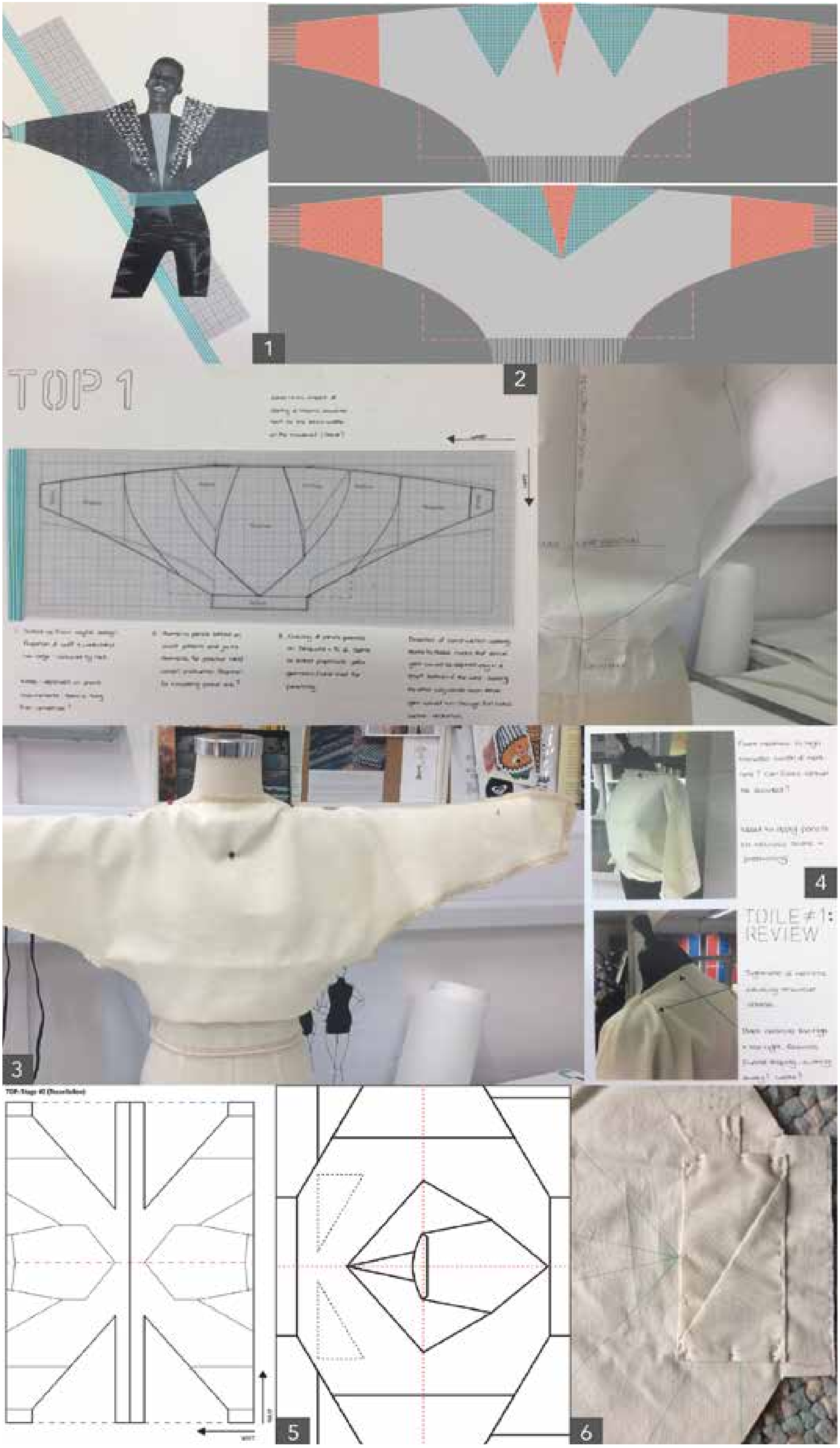


Figure 7.37: Hybrid Top Production Process (2018)
Photographs by Anna Piper


7
8
9
10
11
12
13
14

Figure 7.37: Hybrid Top Production Process (2018)
(Continued) Photographs by Anna Piper

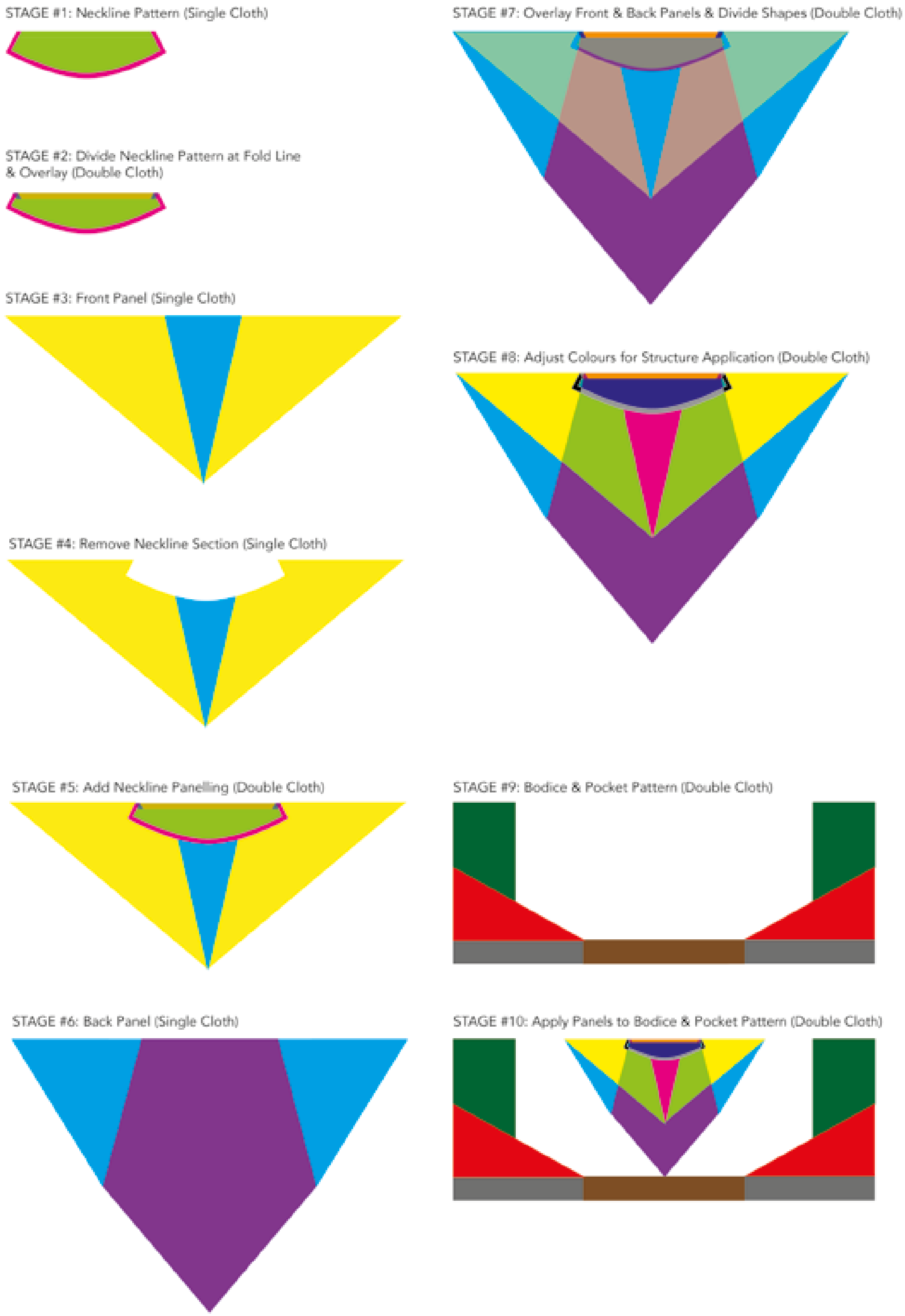


Figure 7.38: Top Digitisation for Pointcarre: Stages of Construction (2017)
Illustration by Anna Piper

combining single and double cloth construction, the use of multiple weave structures with differing float lengths and structural characteristics, as well as inconsistencies in beating down the weft during weaving. Whilst disappointing, the garments were finished and analysed for their success in other areas (Sections 7.9.2, 7.9.3 and 7.9.4), with the lessons learned (particularly in relation to checking garment dimensions during weaving) carried forward into the subsequent coat digitisation and production (see Journal Excerpt 7.10 for reflections on this experience). Details of modifications made to the digital pattern to achieve the correct garment dimensions, along with further alterations to refine the garment design are supplied in the following sections.

7.9.2 Application of Sustainability Principles

Each garment consists of a number of components:

- **Top #1:** the composite body and sleeve component and four triangular pocket pieces.
- **Top #2:** the composite body and sleeve component, two sleeve cuffs and four triangular pocket pieces.

The composition of the two tops produced differs, with Top #1 constructed entirely using 30/2ne combed cotton using waffle weave structures to shape the cuffs and waistband, and Top #2 composed of combed cotton and Lycra (used to integrally shape the cuffs), with cotton bias binding applied to finished the edges of the adjustable waistband ties. As a result, Top #2 is not suitable for end of life recycling, whilst Top #1 is both fully recyclable and biodegradable. By using composite construction for the primary component of both garments (the body and sleeves) a number of seams were eliminated, and the time and resources required for making up the garments was minimised; achieving efficiencies in fabric production and garment construction.

The pockets were devised as a means of utilising the waste fabric from below the sleeves to create a zero waste design, and so the dimensions of the pockets were determined by the depth and angle of the sleeves. The result is a rather large and clumsy double layered front pocket, which I elected not to attach to the final garments to achieve a "better and more successful design" by balancing "the aspiration to waste as little as possible" against the suitability and success of the overall design (Roberts 2014). The fineness of the fabric (discussed in greater detail in Section 7.9.3) and the seamline across the bias of the cloth resulted in some movement and stretch when constructing the pocket. These issues could be remedied by using single cloth construction in these areas to form a denser fabric and a single layered pocket, as well as applying a shrink fibre (such as shrink polyester) in this section of the pattern to reduce pocket dimensions. This would, however, further compromise the ability to recycle the garments efficiently.

7.9.3 Application of Functional Design Principles

The garment shape, with its batwing style sleeve, is designed to accommodate the multi-plane movements of the shoulder and elbow, this is combined with the use of a waffle weave structure across the shoulder to introduce a degree of stretch to facilitate freedom of movement and comfort. In Top #1 a smaller scale waffle weave structure applied to the sleeve cuffs subtly gathers and tapers the sleeve, whilst in Top #2 the gather is increased by inserting Lycra to form a stretch ribbed cuff.

Both designs feature the same seamless functional front and back panels. The multi-structure panels are designed to mirror the sweat patterns of the female body, with an open huck lace weave positioned in the areas where the highest levels of sweating occur. Used in conjunction with the combed cotton fibre and loose fitting garment design, the panels are designed to facilitate ventilation and airflow around the body, to allow it to cool and dry. The simultaneous design and construction of the textile and composite garment eliminates the needs for seams between each panel and weave structure, resulting in a smooth transition between structures to reduce bulk/weight and enhance comfort as there is no risk of irritation due to seams rubbing and causing chafing. The use of an ecru coloured weft in combination with the TC2's grey cotton warp, whilst conservative and restrained, enhances the contrasting visual characteristics of the weave structures and panelling to provide aesthetic interest. The dominant triangle shaped panels echo the garment's loose fitting batwing silhouette. This strong geometric effect and clean lines are, however, softened by the fluidity of the garment's drape.

The openness of the cloth, created by the use of double cloth construction, permits the required amount of yarn movement and contraction to integrally shape and open-up sections of the cloth (Figure 7.39), whilst retaining a light handle and a soft smooth drape. Incidentally, the unintended increase in pick-rate that has adversely affected the

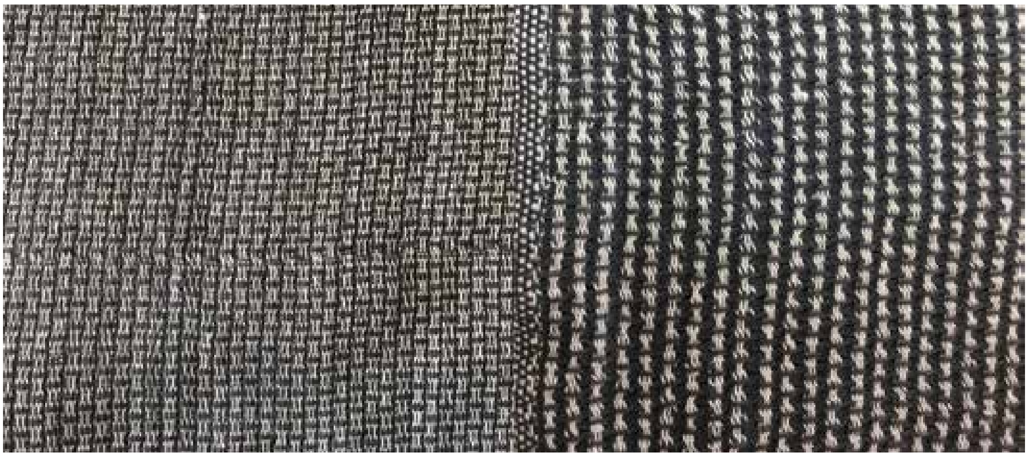


Figure 7.39: Sleeve Panel Before and After Finishing: Loom State (Left) and Finished (Right) (2018) Photograph by Anna Piper

dimensions of the garments, has had a positive effect on the functional durability of the cloth, with the hopsack (or basket) structure providing a stable and lightweight fabric in the areas that surround the functional panels. The application of a tight 2/2 twill structure in the seam allowances has guarded against the excessive fraying experienced when constructing the Jacquard woven trousers. The addition of seam allowances gives clarity to the cutting lines between the waistband, sleeve and pocket panels.

7.9.4 Garment Design and Process Potential

Whilst ultimately unsuccessful, as the correct garment dimensions were not achieved, elements of the design have been a success, and the garments illustrate the potential of the CPW system to integrate multiple textile characteristics and properties within engineered garment and lay-plan designs. The methods devised to integrate functional panelling and integral shaping within a composite garment have proven to be effective, with a combination of non-specialist design software (Adobe Illustrator) and specialist weave software (Pointcarre) used to create a digital (2D design) and produce a physical 3D double-layered garment, which minimises seams, cutting and off-loom construction. The garment design itself is relatively simple due to my limited fashion design skills and capabilities; through collaboration with a more experienced fashion designer, garments of greater complexity with greater functionality and advanced styling could be achieved.

The process of designing and constructing the garments, has highlighted some of the limitations of CPW and of composite garment weaving particularly when restricted to working with a predetermined warp. The selective positioning of 'active' yarns to integrally shape the garment is confined (in this research) to a single direction, with these types of yarns only being possible in the weft. Greater flexibility in lay-plan and garment design could be achieved if the warp was designed for a specific garment design, as 'active' yarns could be strategically positioned in the warp. This is not without its challenges and implications; the 'active' yarns would either be continuous throughout a section of the pattern/lay-plan or would need to be woven intermittently. Although this would be possible, sections of unwoven warp would need to be cut away, thus generating waste.

The failure to produce the garments with the correct dimensions has inhibited the ability to assess the functionality of their styling and fit, but this has not precluded the evaluation and analysis of the suitability, functionality and durability of weave structure and yarn combinations. Drawing on the findings from the production of the Jacquard woven trousers and dress, the addition of seam allowances and application of weave structures has enhanced the functionality, stability and durability of the textile and garment as well as alleviating the excessive fraying of fabrics during garment make-up.

It was not possible to re-produce the tops to achieve the correct dimensions within the time constraints of the study. However, this could be rectified by altering the scale of the digital design to reflect the weft density/pick rate achieved in the top prototypes (i.e. increasing the height of the Pointcarre pattern to 3490 pixels from 2475 pixels).

Although it is disappointing not have produced garments with the intended (and accurate) dimensions, this failure was a pivotal point in the research, and contributed to one of the most significant findings of the study. It highlighted the vital importance of building a relationship with the loom - getting to know and understand the equipment in order to identify and accommodate its tolerances and limitations (Section 7.11). Furthermore, it initiated a change of approach when working on the TC2 loom to construct the final garment prototype (the coat) – moving from a digital approach and a mindset of unflinching trust in the accuracy of the digital programming, towards a hand weaving approach of actively responding to, measuring and checking the design as it was being constructed (Journal Excerpt 7.10).

Working with the TC2 to produce a garment for the first time, I had viewed it as a digital piece of equipment, with the mathematical calculations and digital programming of the garment(s) design being seen as the most critical point in the processes. In doing so, I disengaged with the weaving process, (wrongly, in retrospect) expecting that the digital design, along with the automated tensioning and advancement (winding on of the warp), would result in the correct programmed dimensions being achieved. Despite having to manually insert the weft yarn, I approached production on the TC2 in the same way as I approach weaving on the Jacquard power loom (i.e. by producing a small sample to confirm the weft density and then proceeding to construct the garment) rather than by periodically measuring the fabric during construction as I would when weaving on the hand loom.

7.10 Garment #6: Coat

The coat was developed in response to the t-shirt, dress and jacket designs, using their construction and dimensions as a starting point for design. The design incorporates curved components, gussets, quilted bodice and lined sleeves; capitalising on the TC2's single-end control and manual weft insertion to produce a heavy weight outer and light weight lining. The coat is both visually and physically connected to the t-shirt; using the same cotton yarn and colour palette as well as integrating the warp waste, from the t-shirt production, in the quilting of the coat. The combination of double and single cloth construction, multiple weave structures, quilting and different fabric weights was designed to test the capabilities of the loom. Garment construction was challenging and exposed some of the limitations of composite pattern and garment weaving.

7.10.1 Design and Production Process: Hybrid Weaving

The approach to design was the same as the one employed for the design of the t-shirt and jacket. The ideal dimensions and shape of the individual elements were established and adjusted to tessellate effectively. The width of the warp demanded the production of a multi-piece rather than a single-piece pattern to accommodate long sleeves, as well as determining the direction of weaving, lay-plan configuration and the inclusion of additional design features (such as pockets). With the warp waste remaining unused from the production of the t-shirt, the coat was designed to be constructed using the same 6/30ne cotton to allow the waste to be integrated. The desire to utilise this warp waste triggered the idea to quilt the bodice section of the coat by creating channels using double and single cloth construction and using the waste yarn to fill the channels. The construction and quilting of the fabric whilst it is on the loom, combined with the limited time spent using and familiarising myself with the TC2, led to complications in production.

Informed by the experience of producing the top(s) and not achieving the correct garment dimensions, the fabric was measured frequently during the weaving process. Part way through the construction of the coat inconsistencies in the garment dimensions became apparent, with some sections being correct and others shorter than anticipated. Despite this I chose to continue to weave the garment, with a view to using it as a test piece for analysis before constructing the final prototype. On completion the design was 58.5 inches rather than the intended 81 inches. Whilst a small amount of shrinkage was to be expected once the fabric was no longer under tension, and the quilting of the channels could account for some reduction in length (something that I had not factored into the design) the full extent of the dimensional difference and its inconsistency across the length of the cloth could not be accounted for. The area of most concern was indeed the quilted section, which was calculated to be significantly shorter than required. In response the dimensions of the design were recalculated to increase the patten by 38% and the automatic advancement (wind-on) of the warp beams was adjusted.

A short section of the new design was woven and the pattern was found to be significantly elongated. On removing the tension of the fabric only a small amount of shrinkage was identified (0.75 inches). Reverting back to my established process of calculating pattern dimensions based on pick rate, the design was resized for a fabric density of 16 picks per inch[11]. This alteration was partly informed by the fabric density and dimensions of the first and second attempts and the anticipated shrinkage. However, in the absence of a clear and confirmed reason for the issues being encountered, it was also based on gut feeling.

Initially the change had a positive impact, the correct dimensions were being achieved. However, as weaving progressed sections of the warp were slackening (something that had not occurred during the production of the first iteration). This began to impact on

[11] The original design was based on 14 picks per inch and the second iteration was at 20 picks per inch.

Component	Intended Size	Version #1	Version #2
Body	48″	33″	54.5″
Sleeve	19″	12.5″	18.5″
Lower Sleeve #1	19″	13″	18.5″
Lower Sleeve #2	19″	13.5″	21.5″
Side Gusset #1	6″	4.25″	6″
Side Gusset #2	6″	4.5″	6″
Pocket #1	14″	12.5″	15.25″
Pocket #2	10″	9″	9.5″
Facing #1	2″	1.5″	2.5″
Facing #2	2″	2.5″	2.5″
Collar	10″	9″	9.5″

Table 7.7: Coat Dimension Discrepancies

the quality of the construction, the density and dimensions of the fabric, particularly on the left side of the loom. Had the design consisted only of rectangular blocks, it would have been possible to correct the dimensions by adding or skipping picks in the digital design, but as the coat features a curved hemline this was not possible without further distorting the design. The full design was woven and the garment, despite the inaccuracy of some components, has been constructed. The inconsistencies in the dimensions in the pieces produced are outlined in Table 7.7. The design and construction process are illustrated in Figures 7.40 and 7.41, and reflections on the weaving process appear in Journal Excerpts 7.11, 7.12 and 7.13.

Due to time constraints re-weaving the design was not an option, and therefore a number of issues with the design remain unresolved. However, the outcomes and experience has highlighted some of the limitations of the CPW system and single-piece/composite garment weaving in general; in particular the constraints it imposes on weave structure and fabric combinations and the ability to achieve the required lay-plan and garment accuracy. Both of which impact upon the system's flexibility and efficiency. These issues and their implications are discussed further in Sections 7.10.4 and 7.11.

Figure 7.40: Hybrid Coat Production Process (2018)
Illustration by Anna Piper

7.10.2 Application of Sustainability Principles

Inevitably, in an experimental and developmental process waste was produced as a result of weaving the garment (and sections of the garment) a number of times, and the inaccuracies in the final lay-plan resulted in a small amount of cutting waste being produced during garment make-up. In addition to being designed to eliminate cutting

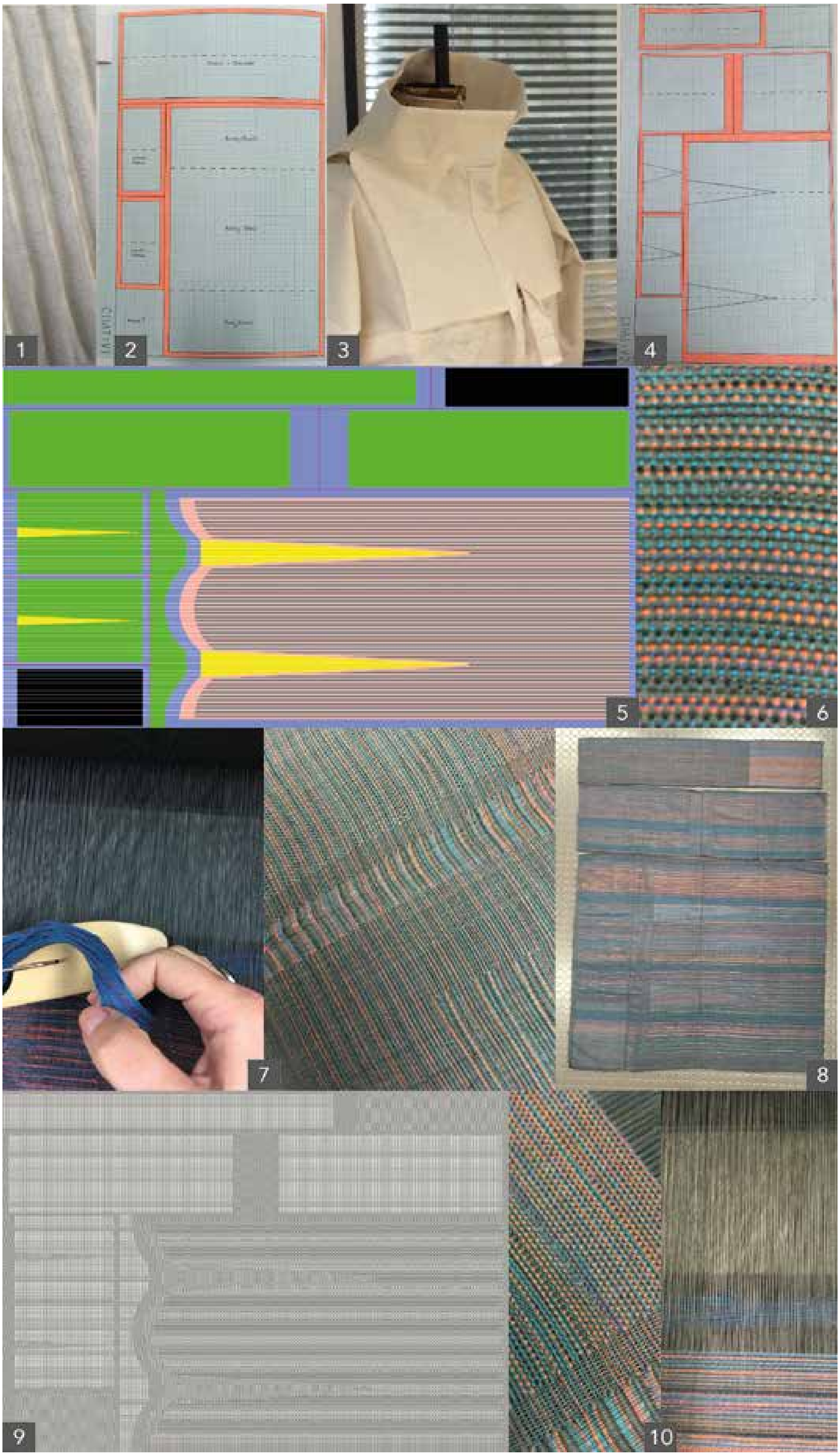


Figure 7.41: Hybrid Coat Production Process (2018)
Photographs by Anna Piper

Figure 7.41: Hybrid Coat Production Process (2018)
(Continued) Photographs by Anna Piper

waste and minimise material consumption, this particular garment was developed to accommodate and utilise the warp waste produced when weaving the t-shirt, thereby closing the loop in the production process. The use of waste yarn to quilt the garment was inspired by the Japanese tradition of using Kibiso fibres to fill futon mattresses and pad garments.

> Throughout history people have repurposed silk waste – from processing broken filaments for padding garments and futons to spinning them to make longer filaments for weaving.
>
> (Brown & McQuaid 2016: 27)

As the waste yarn was being used as a filling, the differing lengths and colours of yarn could be utilised. Although there was a significant amount of warp waste generated during the construction of the t-shirt, it was not enough to quilt the entire body of the coat and so it was supplemented with new (non-waste) yarn. By working with 30/2ne combed cotton in the warp and weft and electing to use the same 6/30ne cotton used to construct the t-shirt as the weft yarn, the coat combines two different weights of cloth whilst retaining its mono-materiality.

7.10.3 Application of Functional Design Principles

Despite the inaccuracies in the lay-plan dimensions and the complications experienced during the weaving of the coat affecting the quality of the garment construction and the durability of the fabric (in places), the coat incorporates a number of functional features that do not appear in any of the previous garments:

1. The combination of zips and gussets in the side panels and sleeves taper the oversized geometric silhouette; allowing the wearer to change the fit and shape of the garment to provide flexibility in sizing and styling as well as accommodating varying levels of movement and activity.
2. The design is composed of single-fibre fabrics of different weights. The fineness and smoothness of the lining fabric allows freedom of movement whilst introducing an additional layer to provide warmth. The quilted section offers warmth; maintaining a good level of malleability to not inhibit movement. The heavier weight

outer fabric is compact and durable, with smoother more flexible weave structures, positioned in gussets and facings, to reduce bulk.

Tighter weave structures are applied in the seam allowances to guard against fraying during garment make-up, with cutting lines indicated with changes in weave structure. Where double cloth construction is used to form the quilting, the fabric is more open. As such, the weft colours were selected to match those used in the t-shirt, so that they would disguise and blend with the waste yarn being used to fill channels. The weft consists of three yarns of different colours (combinations of orange, turquoise, grey, black and blue), generating a mottled effect in the fabric as the colours change and mix throughout the cloth. If multiple garments were produced applying this technique, each piece would be unique, as the yarns are randomly selected and combined. This colour mixing does however reduce the clarity of the cut-lines and seam allowances.

7.10.4 Garment Design and Process Potential

The coat design, with its combination of multiple components, weave structures and especially the quilting of the body, has proven to be (currently) beyond the capabilities of the TC2 loom. Whilst the prototype has demonstrated that there is scope to combine multiple fabric weights and types within a single lay-plan, further work is required to overcome and rectify the dimensional discrepancies between the intended digital design and the physically woven pattern, and to address the evident need to adjust the tension of sections of the warp during weaving. The issues with warp tension impacted negatively on critical elements of the design: the accuracy of dimensions, the quality of weaving and the functional durability of the fabric. Additionally, the inconsistencies in tension and dimensions resulted in the generation of cutting waste during garment make-up, as it was necessary to cut garment components to the correct size to construct the coat.

It was envisaged that the TC2 loom's manual weft insertion, combined with single-end control and non-repeating warp, would eliminate the limitations of hand and digital power loom weaving (Section 7.2). However, the experience of weaving the coat (and the top – Section 7.9) using the TC2 exposed a number of unforeseen obstacles:

- The automated advancement of the warp beams during weaving results in a lack of (manual) control over the warp tension during weaving, leading to inconsistencies in fabric density (pick rate).
- The use of two predetermined 42 inch warps operating together cannot accommodate weave structures with significantly varying/ different tensions, as individual sections of the warp cannot be tensioned independently.

Given more time and further research, it may be possible to establish greater control of the warp beam advancement, countering some of the issues experienced during the construction of the coat[12]. However, the identification of these two interconnected construction limitations has resulted in a greater appreciation of a key principle of woven construction – the use of a continuous warp under tension – and the restrictions this can place on weave structure selection and combination. Furthermore, the problems encountered during the coat's construction have underlined the following advantages and differences of hand and digital modes of production:

- The increased control provided by manual warp winding and adjustment of tension on the hand loom.
- The consistency of weft density provided by the Jacquard power loom.
- The ability to wind individual sections of the warp on different beams on the hand loom; allowing them to be tensioned independently to accommodate variations in weave structure density and tension.

As a result, the process of weaving on the hybrid loom altered my perceptions of hand and digital modes of construction by exposing their hidden potential; some aspects of hand and Jacquard power looms, that were previously perceived as limitations, have actually been advantageous, and provide new avenues and opportunities for exploring and overcoming the issues experienced during the production of the coat.

[12] The advancement of the TC2's front and back warp beams is controlled digitally. The setting for the TC2 is numerical, with the setting increasing to accommodate thicker yarns e.g. a setting of 960 for 8 PPI and 120 for 73 PPI . As such, it may be possible to lower the speed of advancement to a negligible amount and then use the peddle to wind the warp on to achieve the desired tension.

7.11 Technical Application and Outcomes: Conclusion

This chapter has discussed in detail the technical development of techniques, processes and practical outcomes of the research. The change of focus in the research, instigated by unforeseen delays in the installation and availability of the TC2 hybrid loom, led to the Garment Construction phase concentrating on the production of composite woven patterns/lay-plans rather than composite woven garments incorporating integral shaping. Producing woven lay-plans which are cut and constructed off the loom resulted in only a small number of the integral shaping techniques developed in the Component Construction phase being utilised in the final garment prototypes, as the garment silhouettes were shaped largely through cutting and stitching.

A number of successful garment prototypes have been produced using a simple geometric two-cut, two-seam pattern which were adapted to accommodate the specification of the looms being used and the different types of garments being produced. They applied sustainable design strategies and functional design principles to guide and inform decision making, process development, material choices, weave structure selection and garment design. The relative simplicity of the garment designs reflects both the complexity of simultaneous textile and garment production, and my limited fashion design skills and experience. As such, the potential of integral shaping and the ability to incorporate complex curves and shaping using single-end control has not been fully realised. The garment prototypes, therefore, expose the potential of CPW and provide a basis for further research. They also highlight some of the limitations of CPW and draw attention to the constraints of woven construction when applied to constructing garments of this nature, including:

- The continuous warp lacking the flexibility to accommodate some weave structure combinations with differing tensions and densities (see Appendix 8 for weave structure compatibility).
- The inability to predict and achieve the accurate dimensions so fundamental in pattern cutting and fashion design.
- The rigidity of positioning 'active' yarns and structure horizontally (in the weft) and vertically (in the warp) rather than diagonally, determining the configuration of the lay-plan and direction of weaving.

Figure 7.42: Garment Prototypes (2018)
Photographs by Anna Piper

The complexities of designing and constructing textiles and garments simultaneously, the limitations outlined above, and the issues experienced when constructing garments, particularly when working on the unfamiliar TC2 loom has resulted in a number of the garment prototypes being ultimately unsuccessful. However, the transitional approach to design and production has allowed for the findings, experiences and outcomes (positive and negative) to inform, influence and shape subsequent and concurrent designs and outcomes. Furthermore, the experiences and issues encountered have given insights into my application of knowledge and skills, and my approach to design when working with different modes of production. Critically, it exposed the importance of getting to know and building a relationship with the loom, in order to establish, appreciate and navigate its tolerances and limitations. This is fundamental to the maker's ability to design, predict and create successful, high-quality outcomes.

7.12 References

AAKKO, M. & NIINIMAKI, K. (2013). 'Experimenting with Zero-waste Fashion Design'. In: NIINAMKI, K. (Ed). (2013). *Sustainable Fashion: New Approaches*. Helsinki: Aalto University. pp. 68-79. Available at: https://shop.aalto.fi/media/attachments/1ee80/SustainableFashion.pdf Accessed: 12 July 2018.

ALDRICH, W. (2008). *Metric Pattern Cutting for Women's Wear.* (5th Edition). Oxford: John Wiley & Sons.

ASHDOWN, S, P. (2011). 'Improving Body Movement Comfort in Apparel'. In: SONG, G. (Ed.). *Improving Comfort in Clothing*. Cambridge: Woodhead Publishing. pp.278–302.

BROWN, S. & MCQUAID, M. (2016). *Scraps: Fashion, Textiles, and Creative Reuse*. New York: Cooper Hewitt.

BURNHAM, D, K. (1973). *Cut My Cote*. Toronto: Royal Ontario Museum.

CARRICO, M. & KIM, V. (2014). 'Expanding Zero-Waste Design Practices: A discussion paper'. I*nternational Journal of Fashion Design, Technology and Education*. 7(1). pp. 58 – 64. DOI: 10.1080/17543266.2013.837967.

CLARK, A. & CHALMERS, D. (1998). 'The Extended Mind'. *Analysis*. 58.1. pp. 7–19.

CORBMAN, B, P. (1983). *Textiles: Fiber to Fabric.* (6th Edition). London: McGraw-Hill.

DALGAARD, L. (2012). *Magical Materials to Weave: Blending Traditional & Innovative Yarns.* Translated by Ann Richards. Vermont: Trafalgar Square Books.

FIELD, A. (2008). *Collapse Weave*. North Pomfret: Trafalgar Square Books.

MCQUILLAN, H. (2011). 'Zero Waste Design Practice: Strategies and Risk Taking for Garment Design'. In: GWILT, A. & RISSANEN, T. (Eds.). (2011). *Shaping Sustainable Textiles: Changing the Way we Make and Use Clothes.* London: Earthscan. pp. 83-97.

RICHARDS, A. (2012). *Weaving Textiles That Shape Themselves.* Ramsbury: The Crowood Press Ltd.

RISSANEN, T. & MCQUILLAN, H. (2016). *Zero Waste Fashion Design*. Lonndon: Bloomsbury.

ROBERTS, J. (2014). 'Zero Waste Questionnaire'. *Subtraction Cutting by Julian Roberts.* Available at: https://subtractioncutting.tumblr.com/post/86887883276/zero-waste-questionnaire. Accessed: 26 May 2018.

SCANLAN, J. (2015). 'Pathmakers: Women in Craft, Art and Design Mid-century and Today'. *The Journal of Modern Craft*. 8(2). pp.109-114.

SPENCER, D, J. (2001). *Knitting Technology*. (3rd Edition). Oxford: Pergamon.

THOMAS, L. (2009). 'Woven Structures and Their Impact in the Function and Performance of Smart Clothing'. In: MCCANN, J. & BRYSON, D. (Eds.). (2009). *Smart Clothes and Wearable Technology*. Cambridge: Woodhead Publishing in Textiles. pp.131–155.

WATKINS, S, M. & DUNNE, L, E. (2015). Functional Clothing Design: From Sportswear to Spacesuits. London: Bloomsbury.

WILSON, J. (2001). *Handbook of Textile Design: Principles, Processes and Practice*. Cambridge: Woodhead Publishing Ltd.

WRAP. (2017). 'Sustainable Clothing: A Practical Guide to Enhancing Clothing Durability and Quality'. *WRAP*. Available at: http://www.wrap.org.uk/sites/files/wrap/Sustainable%20Clothing%20Guide%202017.pdf. Accessed: 20 September 2017.

7 Journal Excerpts

Trouser Design – Development of Ideas (Sketchbook Annotation 7.1)

Hand Production

- *Curve could be reintroduced by using clasped weft polyester shaping – what does this add for fit or look?*
- *Clasped weft used to create gusset – coloured warp yarns could be used as shaping guides and intersections at the point of clasp to provide cutting line – PPI would need to be very constant and accurate.*
- *The waistband:*
    - *Woven as double cloth tube (double depth to fold over)*
    - *Block threading for warp/weft shrink – Lycra or polyester? Would the stretch of Lycra be needed to get on and off?*

Jacquard

- *Different weave structures used to create seams and cutting lines*
- *Partial clasped weft not possible to shape the inside leg*
- *Seam needed at either side of double cloth waistband to join – impact on attachment to top?*
- *Would dimensions fit the weaving width? Trouser leg could be narrowed to accommodate*
- *Pros: structure and sizing accuracy and consistency, pattern and panelling options, possibility of adding additional shaping structures to control fullness as well as pattern detail*
- *Cons: half-scale on university loom, use of multi-fibre due to cotton warp*

Weaving Options

The width of the pattern happens to fit the width of the Jacquard repeat. It could also be produced in double cloth to eliminate stitching on the waistband – any benefits of the waistband being integrated into the leg pattern piece?

- *Option of adding shaping at the ankle*
- *If woven in single cloth could pockets be integrated?*
- *Scope for weaving in channels for drawstrings*
- *Would be no need for warp markers for shaping*
- *Could apply more varied durable structures*

Dress Design – Panel Placement Options (Sketchbook Annotation 7.2)

As the Jacquard has a triple-harness repeat the dress needs to accommodate/ utilise this repeat. So functional elements will need to appear in some places as decoration. The main feature will be the neckline. I need to think about how the cut and fold lines will be differentiated within the repeat.

The Jacquard also determines the width of the warp and therefore the dimensions of the dress. Because of this the dress will have to be small – I am working towards a size 6 or extra small.

The shaping will come at the waist and the hips and this will be achieved using a series of elongated triangles in a shrink/stretch waffle weave. I have played around with the scale of the triangles and they are larger than I had envisaged but I wanted a central triangle at the front and for the side fold to be either between two or at the centre of a triangle. The larger panels have a greater sense of balance and simplicity. The aim is that they will taper the skirt out from the waist but the stretch panel at the hem will bring it back in (more like a tulip style).

The dimensions draw from the first version of the t-shirt (sleeve depth) and the rounded neckline of the original top. The challenge, as I have seen with the trousers, will be weaving the correct dimensions. What is particularly difficult with this design is that I can't recreate the 'activity' of the waffle weave in a toile. So, I am going to go straight to the weaving based on toiles from other designs. It's all measurements and informed ideas.

Top Design – Review Before Production (Sketchbook Annotation 7.3)

Review of structures and calculations before production. So far, the digital pattern has been transferred to and been cleaned up in Pointcarre. It should be possible to alter the scale of the pattern to H2475 x W3960, and for the individual components of the design to be scaled automatically i.e. without individually calculating each dimension. The seam allowance can then be applied.

Pattern scale is based on: *Width – total ends on warp*
Height – PPI of 45

In reviewing the structures, I realised that the rib structure intended for the cuffs couldn't work with a stretch yarn applied as it is in the wrong direction (warp). So, an alteration has been made to the pattern to apply the cuff at the edge of the sleeve, rather than as separate pieces. As this design has not been tested on the loom it makes sense to try different design options in each of the garments. It is not necessary for them to be the same even though they are being woven simultaneously.

Trousers: Warp Threading (Excerpt 7.1)

Posted: 11th December 2017

It's taken a couple of full days to thread the loom for the trousers. The first few inches were a nightmare with the multiple coloured yarns sticking together – I was having to stand and lean right over the shafts to separate the yarns and so it was back-breaking work for a while. But once I got through the coloured yarns and moved on to the grey section it became much easier. These yarns were warped in twos and this seems to just make the yarns separate more cleanly [...]

I have found myself sectioning the warp for threading by using the bundles in the raddle. This is not something I have done before, but it has proved to be quite useful. At one point it revealed that I was short by two threads – I had missed a couple of threads when warping – this allowed me to add in another few ends. Luckily this was in the grey section and so I could simply add a couple of threads. Right at the very end of the warp I am short by one end, so I am not sure what has happened there. I also finished threading at a point in the pattern that was unexpected. I had calculated that there would be three repeats over shafts 9-16 right at the end of the warp but there were only two. I have quickly checked the bundles of threaded ends alongside the colour coding and it all appears to be OK.

I am hoping that these errors will be picked up during reeding and that they are close to the end of the threading so that I don't have to undo too much! I think that this is the most complex warp I have ever threaded – not because the threading itself is complicated but because the colours and the accuracy of their placement is so important. I am really nervous. I don't normally question myself and my calculations to the extent I am doing now, but I am now so pushed for time that I really can't afford any disasters!

Tagged: *Errors, Expectation, Pattern, Questioning, Time*

Trousers: Reeding and Waistband Weaving (Excerpt 7.2)

Posted: 12th December 2017

I have been apprehensive about weaving partly because of the potential errors mentioned before, but also because the loom I am working on has its problems – the main one being an inconsistency of tension. I took a gamble working on this loom rather than one of the university looms as I can access it at the weekends and evenings. After weaving the first 4 inches, which went pretty well, my fears were confirmed – the tension was a disaster. The warp yarns were sticking and so loose that getting a clean and consistent edge was almost impossible. I have taken to only winding the warp on a small amount each time and to beating down with the reed a couple of times before inserting the weft to try to separate the yarns. This is working to some extent but there are still some flaws in the cloth which is really annoying but they can be fixed if necessary.

It is so hard to ensure no faults are occurring. There was one end that was not lifting correctly and I had to keep removing the pick and starting again. I was concentrating so hard on that particular section that I then managed to miss multiple ends not lifting together at the other side of the warp – this will definitely need to be fixed. It will be quicker to fix than unpick what I have already done.

Another issue is the PPI – it seems to be weaving at about 36-38 picks per inch rather than the 40 I am aiming for. I have no idea why – the EPI is the same, the yarns are the same and I am beating the same as I was when doing the test samples. The only thing that is really different is the width of the warp. At the moment, in the waistband and the unshaped section of the leg, it is not really a problem but it is when I come to the shaped sections as the warp has been coded and the calculations done based on an EPI of 40. I am hoping that as the warp settles I can achieve the desired PPI. If this doesn't happen the overall pattern will be extended and bigger than planned. This will be consistent throughout the pattern and so the pattern pieces should still fit together effectively but it is not ideal [...]

Tagged: *Accuracy, Calculation, Errors, Risk, Weaving*

Trousers: Shaping Sections (Excerpt 7.3)

Posted: 14th December 2017

I have started the shaping sections of the trousers – not easy! It is time consuming, but I have gradually developed a technique. Initially my plan was to insert a coloured yarn at the start of each shaping interval, but I don't think that it will give a strong enough demarcation between the pattern pieces, so I have decided to use white in the gusset sections and then grey for the trouser leg – it has resulted in a stronger pattern shape being produced.

I began using bobbins for the interval sections and the shuttle for the central leg section but have since found that using a loose thread at either edge rather than a bobbin works better. There are no threads sitting on the surface of the cloth and getting mixed up and tangled around each other. Instead the 'interval' or 'shaping' threads can hang down at the sides of the fabric and just be picked up when needed.

Positioning the clasped weft in the correct place i.e. over the specific warp thread at the edge of the gusset sections was initially very tricky. As when the shed is closed and the weft is beaten down the clasped weft moves inwards and out of position. I have discovered that holding the 'shaping' thread taut down the side of the warp when beating helps to stop this happening. This has made things quicker and more accurate [...]

This is a great example of how, when working by hand, plans can simply be adjusted in response to what is happening in front of me – I am able to see what is happening and then alter my calculations accordingly. Had this happened on the Jacquard or the TC2, the whole design would have had to be altered in the weave software to alter the positioning of the shaping intervals.

Tagged: *Calculation, Problem-solving, Responsiveness, Weaving*

Trouser Centre Point (Is it worth it?) (Excerpt 7.4)

Posted: 3rd January 2018

I have just made it to the centre point of the shaping on the gusset panel on the trousers! I have been thinking a lot whilst weaving and when off the loom about the value in this type of construction i.e. shaping panels on the hand loom. It has really highlighted to me that the usefulness of this is quite limited as the structure options are so limited. In this particular pattern/design the fabric quality remains the same throughout (with the exception of the waistband) and the demarcation between panels (i.e. the cutting lines) are not that clear due to the continuous stripes in the warp.

I think that the value in CPW concept really is in the ability to generate multiple patterns and fabric qualities and this can only be effectively achieved using single-end control on the Jacquard or the TC2. The only real way of producing different fabric qualities in different panels on the hand loom is through using different yarn qualities in the weft and using the clasped weft technique to position them, not by using different weave structures (as the threading will not allow for this). It had not occurred to me to do this when designing the lay-plan - it is only through weaving that I have really had chance to contemplate this (even though it is something I tested in the sampling phase).

So, at the moment I am really starting to feel like I am wasting my time with this design! It is hard to keep motivation when weaving. I feel as though the delays I have experienced in waiting for the new loom and then having to change the focus of the research has really knocked things off track - I had lost a sense of purpose and was so desperate to make some progress with the weaving that I felt that hand weaving was really the only option. The massive break between technical testing and then actually being able to apply any of this to designs has meant that momentum and focus was lost.

If I was still working towards producing whole garments, I think the hand weaving would still have a useful and significant part to play as it does offer a lot of flexibility for using different warp yarns which provides both functional and aesthetic options. And importantly, the clasped weft technique does allow for isolated sections of shaping/shrinking (by applying active yarns) to be created in a way that I don't think can be reproduced on the other looms […]

Tagged: *Questioning, Value, Meaning*

Trouser Production: Structures (Excerpt 7.5)

Trouser Production 1 - Posted: 3rd January 2018

[...] In addition to this finding, I also found that a couple of the weave structures are too tight for the pick rate. The 11 end waffle in single cloth is the most problematic and needs to be doubled. I am concerned that the scale of the waffle on the half-scale trouser will be out of place, but I will need to see how much shrink is achieved when the fabric is removed from the loom. The 2/2 twill is also very tight. This has only been applied to the constructed seam in the trouser and so there is not much of it. As such, it can be easily replaced [...]

First Time on the TC2 (some Jacquard in between) - Posted: 2nd February 2018

[...] In between weaving the tests we tried another Jacquard trouser test. I had set the pattern up to weave at 60 PPI, so we adjusted the machine until it was weaving at that rate and then began to weave the trouser pattern. I need to get the design off the machine before I can confirm that we have achieved the correct scale, but it is definitely pretty close. However, we did find that despite increasing the size of the single cloth waffle structure the machine is still struggling with it at 60 PPI. It is not consistent in scale - it is more compacted as the machine transitions from one structure to another. The technician mentioned in passing that there is a pick rate that the loom is happier with for waffle, so I suggested that I readjust the scale of the design to suit the parameters of the machine to achieve a better more consistent construction. I guess this is a bit of a strange thing when using digital mechanised equipment - the machinery can dictate the design. There are just some things that you can't get around - the loom has its own tolerances and whilst you can push them, there are some things that just cannot be overcome [...]

Tagged: *Garment Design, Jacquard Production, Material Engagement, Process Constraints, Calculation*

Dress Design and Digitisation (Excerpt 7.6)

Posted: 5th April 2018

Having woven the t-shirt (still to be made up) I have been working on the dress development. Based on the same lay-plan style as the t-shirt, the dress will be more complicated as I intend to produce it on the Jacquard. This means that I have to accommodate and work with the triple-harness repeat. It also means no stripes or multiple yarn types/colours in the warp.

Having already sketched an initial design a while ago, I have calculated dress dimensions. This has been based on typical/standard sizing measurements and some measurements of dresses that I own (this has really only influenced the length). I have also applied the neckline from the TC2 top rather than starting from scratch with this and have used the t-shirt dimensions as an additional guide. I will be working to a UK size 6/8, not out of choice, but based on the width of cloth, the Jacquard is set-up to produce.

As the garment is going to be integrally shaped using the weave structures, I decided that toileing would be pointless as I am unable to recreate the shrink of the panels and so I have moved directly to programming the design from my dimension calculations. As no toiles have been produced, no patterns have been produced either, so I have drawn the design directly into Pointcarre. Working with the findings from previous test sampling (Phase #1 of the research) and trouser garment production I have selected the weave structures to create the panels - using warp and weft facing structures to demarcate the different panels, seams and cutting lines.

At this stage (i.e. for the first test production) all of the lay-plan is constructed using structure. I have not yet applied any colour coding for cutting and folding. Due to the single colour in the warp and the pattern repeat, I am unsure at this point how to effectively indicate cutting lines etc. as it is not possible to only apply this to the sections of the lay-plan that actually need to be cut/folded (they will also appear in the other two repeats across the width of the cloth). So, I need to decide if colour coding is the best way to go about this, or if I could apply structure coding instead. The advantage of colour coding would mean that I can create an aesthetic/visual connection between the dress and the t-shirt to give the feel of a cohesive collection.

Tagged: *Boundaries, Design, Aesthetics, Digitising, Structures*

Residency: Part 3 (Excerpt 7.7)

Posted: 13th June 2018

It has taken much longer than expected to plan the warp for the final garment, mainly due to the time taken working out the lay-plan for the jacket pattern. The aim was not to produce a single-piece pattern as I have in the other PhD garments. The jackets are more about exploring and engineering patterns within a zero waste lay-plan.I began by working out the required dimensions for each part of the garment (body front and back, sleeves, neckline and facing). The size of the components have been based on existing garments as I do not have the facilities/time here to make a toile (so fingers crossed they will be ok). I then tried to jigsaw the pieces together. Ideally, I wanted the sleeves and the body to be different patterns/colours and so this means that they should be in separate parts of the warp. I also wanted to keep the warp quite narrow (to reduce threading time) but had no specific restrictions for this. But after a while it simply became about fitting the pieces together in whatever way I could to eliminate waste. I had a range of different lay-plans but none completely eliminated the waste - there were awkward and unusable gaps.

I started to break down the components e.g. the sleeves broken into two pieces, the top/shoulder sections separate from the lower body of the jacket. This resulted in a range of other formations and only one that eliminated waste if I added some pocket sections, but it was very wide. But after a night's sleep and some thinking time I came to the conclusion that the more pieces there were the more complicated things became, so I went back to basics, using as few pieces as possible that would require less construction and stitching. Although I was left with a small section of the fabric unused, I have decided that this will be applied as adjustment straps to tighten the cuffs of the sleeves.

The next step was to design the warp (colour placement and shaft allocation) based on the sampling I have done. This process was a little different to the other garments I have produced for the PhD as there are decorative elements in these pieces and there needs to be scope for producing 2 different jackets, each increasing in complexity and decoration. So, I have had to think not only about functional placement of colour and structure but also about pattern placement and possibilities. As the component pieces have different widths the positioning of seams is not consistent across the full width or length of the pattern, so that stripes in the warp and weft do not completely align with seam lines and so I have had to find alternative ways of marking the hems, folds and seams. In the most part (for the main components) this marking of the lay-plan is effective, but it is a little less clear cut on the adjustment straps and the neckline.

Tagged: *Calculation, Construction, Planning, Challenge, Design, Waste*

Digitising the Top Design (Excerpt 7.8)

Posted: 19th November 2017

Today I have spent the day preparing the top design ready to be transferred into Pointcarre. It was much more complicated than I thought - I have really had to concentrate! To start with I had to go back to the neckline section and had to go back to paper and fabric to try to recall how it would work and to consider the impact of doing this in double cloth rather than single cloth.

Putting it onto fabric at full-scale I found that it needs to be a little wider to ensure that it would go over the head without the need for fastenings. I wanted to ensure that there was a clear demarcation of the cutting line and the seam allowance. For some reason it took a while to get my head around the fact that the seam allowance needed to be part of the main garment rather than the flap that is folding down into the top - I needed to cut and fold the fabric and then go back to the fabric piece as a guide when translating the piece digitally. By dividing the shape at the folding line in Illustrator I could then overlay the two pieces as they would need to be positioned to apply the weave structures.

The neckline and the functional panelling of the top are quite complicated (even though they look like a simple design) when producing the garment as a double cloth (rather than a flat lay-plan to be cut and constructed). Different panels of the piece intersect each other at different points which means that they need to be broken up to allow different weave structures to be applied on the front and the back of the garment. For Pointcarre each different weave structure combination needs to be in a different colour. There are 11 different structure combinations in the top, even though overall there are only 5 structures in the garment as a whole. The process of preparing the garment design involved a number of different stages:

- *Overlaying sections in Illustrator - front panel and neckline, back panel, bodice and pockets*
- *Dividing the shapes to apply the colours for the structures*
- *Tidying up, realigning and reuniting sections that have divided incorrectly or become distorted*
- *Working out the structure combinations and allocating colours*
- *Exporting the file to Jpeg format*

Digitising the Top Design (Excerpt 7.8 Continued)

Posted: 19th November 2017

Once the structures were worked out the garment is ready to be digitised in Pointcarre [...]

After completing the digitising, I moved on to winding the warp onto the hand loom. The yarn is so sticky! I have had to rope Neil in to help me but even with his help it is taking such a long time. I think that this is for a couple of reasons - there are a lot of ends (as the yarn has been doubled up) and the warp itself is quite wide and so it is difficult to apply an even tension across the warp when winding. The yarn is sticking together and requires being teased and untangled repeatedly - there is very little furring up of the yarns or any real knots. Only 4ft wound on this evening but that will have to do for the day.

Both processes, hand and digital have their drawbacks - winding on and threading with hand weaving is time consuming and at times backbreaking but digitising the designs for Pointcarre can be equally as frustrating and time consuming.

Tagged: *Digitising, Frustrations, Material Engagement Preparing, Time Weaving*

Back to Production (Excerpt 7.9)

Posted: 9th August 2018

[…] The next to complete is the top, as the TC2 is now ready for use. It is such a long time since I worked on this design and so I needed a review. As a result, I have come up with a few adjustment/developments.

Firstly, I needed to calculate the dimensions based on the pick rate being used. I then needed to add in the seam allowances. So far, the digital pattern has been transferred to and been cleaned up in Pointcarre. It should be possible to alter the scale of the pattern to H2475 (EPI 45) x W3960, and for the individual components of the design to be scaled automatically rather than calculating individually each component dimension.

In reviewing the structures, I realised that the rib structure intended for the cuffs wouldn't work - I was planning to have them in a rib structure using a shrink/stretch yarn to gather the sleeve, as the length of the cuff is in the warp direction (the stretch and shrink yarns can't be in the warp). So, an alteration has been made to the pattern to apply the cuff at the edge of the sleeve rather than as a separate piece. Drawing out the design to capture these changes I planned to construct the main body of the top in plain weave, however, on reflection I think that it should be in 8/5 satin. This will mean that the top will match the dress already constructed on the Jacquard. This makes the allocation of weave structures in Pointcarre a little more complicated as the front of the garment will require a weft-facing structure and the back will need a warp-facing structure so that both sides of the garment will be the same. I will also use an ecru cotton in the weft to work alongside the grey warp. This will then help to visually match the two garments as the dress is woven on an ecru warp with a grey weft.

As the design has not been tested on the loom it makes sense to try out different design options in each of the garments. It is not necessary for them to be the same even though they are being woven simultaneously. So, the sleeves and cuffs will be different. The waistband will also be different to accommodate these differences - one will use a stretch waffle to shape, the other will use ties to adjust.

Tagged: *Analysis, Design, Review, Digitising*

Disaster and Disappointment (Excerpt 7.10)

Posted: 19th September 2018

[…] I should have measured the garment during construction, rather than trusting the digital design. This is a crucial point. I have (I now realise) been over-reliant on the digital design, trusting it to be correct based on my calculations, programming and sampling outcomes. This is something I would never do when weaving on the hand loom – I am aware that variation in the density of the cloth and pick rate are relatively common – I don't just count the number of picks as I weave, I measure and adjust the number of picks accordingly to achieve the correct dimensions, I respond to the design being constructed in front of me. If things don't look right I check them and correct them where necessary.

I thought, until this point, that the critical part of the process when working on the hybrid loom was the programming – the calculation of the dimensions based on the required garment size and the number of picks per inch. But, whilst this certainly is very important, so is the actual weaving. It appears that I had, in effect, abdicated responsibility for the design once I had completed the digitisation of the design, thinking that I was going through the motions of weaving a predetermined (or programmed) design. When in reality, I should have been engaging with the process, applying the same principles and approach to this digital form of construction, that I apply when hand weaving – responding to the design and the fabric, trusting my gut instincts.

Unfortunately, there is just not enough time to reproduce the tops, but they have proven to be a massive learning curve. They will change my approach when working digitally. Despite being the wrong size, the tops are not in fact a complete disaster. The weaving of the pieces as composite garments has been successful, the panelling is particularly effective. Even though the programming was complex I managed to achieve complex double cloth panelling with a smooth and seamless transition between weave structures – this is the most complex garment digitisation I have completed to date.

Tagged: *Digitising, Material Engagement, Mistakes, Problem-solving, Expectation*

Reaching the Right Dimensions (Excerpt 7.11)

Posted: 20th September 2018

[...] So, rather than working with the pick rate to recalculate the design (which hasn't worked with this or the top design), I increased the design by percentage (this equated to 20 PPI). I also adjusted the advancement on the loom (the winding on). This time the design was significantly too long - a third of an inch each inch (but this is not entirely consistent).

Whilst doing this, it occurred to me that the stuffing of the tubes would take up some of the cloth and therefore reduce its length. So, I took the tension off and measured the fabric again, to find that it relaxed back by 0.75 inches. I also measured the actual number of picks per inch, it was 14 PPI! But I already know that when weaving the design set-up for 14 PPI it weaves too short. In hindsight, adjusting the pattern and the advancement between tests was an error, as it muddies the waters as to how much impact each change had.

My gut feeling was, that if I changed the design for a pick rate of 16 PPI, it would allow for the shrink back when the tension is removed. This may not achieve 100% accuracy in the design but at this stage slightly bigger is better than another design that is too small. So, I have gone with this and the design is weaving slightly longer (approximately 1 inch over 20 inches) but I think that this is manageable. Once I am past the main body of the coat (the stuffed curved section) I can do what I would do on the hand loom i.e. reduce the number of picks if the design is weaving too long or increase the number of picks if it is not long enough if necessary. But I can't do this in the more complex areas of the design - the pattern is not a repetition of the same structure throughout, it is a refined and more complex shape. Adding or reducing picks would alter (and even ruin) the curve, the quilting channels would be too narrow or too wide, the positioning of the gussets would be altered etc. Basically, because the pattern piece is not a rectangle containing a single structure, it can't be altered without altering and scaling the digital pattern.

This experience highlights a number of issues with the weaving of the garment and/or lay-plans, where the accuracy of the design is critical:

Reaching the Right Dimensions (Excerpt 7.11 Continued)

Posted: 20th September 2018

- *The calculation of dimensions and conversion to pick rate cannot account for the characteristics of the cloth i.e. the differences in tension, the potential reduction, the take-up if stuffing is used etc.*
- *The calculation may be accurate but the variables of the loom (as experienced on the Jacquard) and the potential minor inconsistencies of beating and advancing can have a large cumulative impact across a long garment/lay-plan.*
- *With complex designs, it is not possible to simply respond to the design as it is constructed, re-programming is needed.*

As such, there is no one formula for achieving the correct garment dimensions. The process requires testing, observation, learning and responsiveness, particularly when working on a loom where the weft insertion is not automated. The most predictable method is using the Jacquard, as the weaving density is consistent once set/selected. This doesn't however, remove the need for technical testing to understand yarn and weave structure behaviour.

I had thought that the hybrid loom would allow me to overcome the restrictions of the hand and digital looms, but it actually makes the weaving of garments with accurate dimensions more complicated (more risky). It allows for more complex designs but doesn't have the consistency/accuracy of the Jacquard. Because the designs are more complex, you can't simply add-in or remove picks in response to the fabric construction as you would on the hand-loom. Even with lots of time to test, refine, reweave there is always the potential on the TC2, that the manual hand construction will result in some inconsistencies that could alter the design dimensions. The ideal equipment for CPW (I think) is a Jacquard power loom with a single-harness (and accurate calibration of pick rate selection).

Tagged: *Calculation, Problem-solving, Responsiveness, Structures*

Pushing the Loom to Its Limits (Excerpt 7.12)

Posted: 21st September 2018

Another full day of weaving today. Measuring the garment at strategic points in the construction I am finding that there are some inconsistencies. Having been weaving-up a little longer yesterday, half way through the garment the lower sleeve section was just meeting the correct dimension, but when I reached the top of the second sleeve section there was a significant increase in size. By the central point in the body section the tension on the left side of the warp was becoming very loose, and the cloth was weaving at a lower density. This is due to the differential in the amount of warp being used in the quilted section and the non-quilted section. This was to be expected but not to this extent. Having woven the tests (at the wrong scale) there was no real problem with the tension. Over the full length of the garment I expected there to be some minor issues with tension on that side of the loom as the thicker fabric started to wind onto the front.

This, along with the issues in achieving the correct dimensions, has highlighted the limitations both of the loom and the CPW system itself. The coat was intended to test the system, whilst the garment construction (block-based pattern) is quite simple the design incorporates multiple different fabric qualities, single and double cloth construction as well as curved and gusset sections. All of these elements together have proved challenging for the loom - the different tensions in the weave structure, the stuffing of the channels, as well as any inconsistencies in my beating of the yarns have all impacted heavily on the tension, and as a result, the dimensions and the quality of the weaving (due to loose threads not lifting and lowering) […]

[…] I am disappointed about the current position with the coat design, with a few more inches to weave I already know that the pieces are not going to fit together as planned. Even though it may be possible for me to come up with some creative solutions during garment make-up, overall the design is not successful. Even if I was to weave the garment again, the design would need to change fundamentally to alleviate these problems. Quilting would need to be used across the full width of the warp to avoid the major tension issue or the quilting would need to be removed from the design completely.

Tagged: *Limitations, Structures, Problems*

Findings from the TC2 (Excerpt 7.13)

Posted: 23rd September 2018

The use of the TC2, whilst I had anticipated it would remove the boundaries of other forms of construction, instead it brought its own unexpected limitations:

- *The accuracy and consistency of the digital pattern could not be translated into the woven cloth.*
- *The freedom of yarn and structure usage facilitated by the loom is controlled by the fundamental principles of weaving, which cannot be overcome/ bypassed.*
- *In the time spent work with the TC2 loom, I was able to identify a number of boundaries but not resolve them all (in particular, in consistency in outcomes and dimensions).*
- *Unlike the Jacquard power loom, the hybrid loom does not inhibit the use of structure combinations, but this is not an indication these combinations will be successful.*

This has highlighted to me that knowledge of the specific loom, not just of the wider process and principles is required. The time to get to know the loom, through sampling and experimentation is essential - knowledge of the structure, materials, processes and machine is embodied through experience.

Tagged: *Findings, Learning, Reflection*

8 Conclusion:

Reflections, Findings and Future Research

8 Conclusion:

Reflections, Findings and Future Research

8.1 Conclusion: Overview

This concluding chapter draws together and reflects upon the key findings to evidence the contribution to knowledge that this research has made. The first section reviews the research practice including the creation of the Composite Pattern Weaving (CPW) system and the application of sustainable design principles; identifying the principal technical findings, processes and research limitations, and recommendations for future research. The second section evaluates the Transitional Design Methodology; considering its implementation and the resultant outcomes and findings, as well as identifying opportunities for its future application and development.

8.2 Practice: Reflections, Findings and Recommendations

This research has brought together the disciplines of woven textile design and zero waste pattern cutting by devising and implementing the CPW system (Section 5.6.4). A number of pattern weaving processes, integral shaping and panelling techniques and garments have been developed and interrogated using a variety of standard (un-adapted) looms; exposing both the limitations and the potential of single-piece, fully-fashioned and composite woven garments. The garments uniquely employ and assimilate sustainable design strategies with functional design principles, to minimise waste and material consumption as well as to achieve garment durability and aesthetic desirability to enhance longevity. The key findings are listed below, and are expanded upon in the sections thereafter:

- The ability to produce accurate and functional zero waste garments using the CPW system is contingent on an established relationship (knowledge, understanding and experience) with the loom being used.
- The compatibility of weave structure tensions and densities (openness and tightness) determines shaping, construction and garment design possibilities, thus limiting the types and qualities of garments that can be produced.
- CPW inherently subverts the fashion design process, as the conventional fashion process of design, pattern-cutting and toileing cannot account for the varying qualities, constructions and compatibility of woven structures – multiple productions of developmental garments should be anticipated, as design, toileing and production are integrated and inseparable.
- CPW, used in conjunction with looms with single-end control, has the potential to produce complex garments that include multiple textile characteristics, integral shaping, contoured panelling and engineered patterns, to meet functional, sustainable and decorative requirements.
- Realisation of the full potential of CPW requires equal knowledge and skills in both fashion and weave design.

Through the combined consideration of sustainable strategies and functional aspects of textile and fashion design, my investigation makes a significant contribution to the relatively small existing body of research into fully-fashioned and single-piece woven garment construction. It lays the foundations for future research into composite pattern and garment weaving, identifies areas for further investigation as well as making practical suggestions for those undertaking future research in this area (Section 8.2.2).

8.2.1 Practice Reflections and Findings

The machine(s) and mode(s) of production, the principles of woven construction, the garment prototypes and the application of sustainable design principles contribute to the success (and in some cases failure) of the CPW system, with each offering specific insights and findings (outlined below).

Machine: in addition to the anticipated limitations imposed by the individual machine specifications (lifting mechanisms, weft insertion, maximum warp width and predetermined warps), the practice, by incorporating multiple modes of production (hand, digital and hybrid), exposed my under-estimation of the constraints present in woven construction (see Weaving Processes below) as well as illuminating some unforeseen implications of working with automated and digitally programmed looms:

- The ability to achieve precise garment dimensions and designs is reliant on the accuracy, consistency and calibration of the loom's automated actions and processes i.e. pick rate and warp advancement.
- Digital programming processes and calculations, whilst being effective for one type of loom, may not be directly transferrable to other forms of production, due to the machine's idiosyncrasies.
- The lack of (manual) control of the TC2, over warp tension in particular, inhibits the use of weave structure combinations that otherwise could be compatible and effective.

Having predicted that the hybrid TC2 loom would remove many of the restrictions of hand and power loom production by assimilating single-end control with manual weft insertion (Sections 3.3.3 and 7.2.1), it instead introduced a series of unexpected complications and (as yet) unresolved issues:

- The accuracy of the digital pattern could not be translated into the woven cloth, with dimensional differences being inconsistent through the woven fabric.
- Unlike the Jacquard power loom, the hybrid loom does not inhibit the use of structure combinations, but this is not an indication that the tensions and densities of these combinations will necessarily be compatible.
- The hybrid loom, despite its automation of significant parts of the process, demands a 'hand weaver's approach' – requiring caution, measurement and engagement (Section 8.3.1).

Together, these findings highlighted the fundamental significance of knowing and understanding the loom and underlined the importance of experimentation in advancing practice (Section 8.3).

Weaving Processes: the Component Construction phase (Section 7.3) of the research derived a range of successful techniques and processes for use with hand, digital and/or hybrid looms that were subsequently applied, tested and developed during the Garment Construction phase (Sections 7.4 - 7.10):

- Multiple methods to integrally shape textiles using stretch and non-stretch yarns have been identified and categorised, with selected methods (cellular structures, clasped weft and rib effect) successfully applied to garments.
- Complex seamless panelling of multiple weave structures applied in both single-piece and composite garments, achieved by integrating specialist weave software (Pointcarre) with conventional design software (Adobe Illustrator).
- Functional colour and weave structure coding developed and applied to differentiate between garment components, seam allowances, fold-lines and cut-lines to guide garment construction.

The development of these techniques and their application to garment forms has identified a number of constraints and limitations of woven construction and, therefore, composite pattern and garment weaving. The fundamental principles of woven construction, in particular the continuous warp under tension, control and impede and/or determine the following:

- Weave structure combinations (including the single and double cloth constructions) with differing tensions and densities, as they introduce inconsistencies in warp tension that impact on the quality of construction and the accuracy of garment/component dimensions.

- The direction of weaving and the configuration of lay-plan components, due to the maximum warp width and the positioning of 'active' yarns and structures for integral shaping being restricted to horizontal and vertical (rather than diagonal) planes (i.e. in the warp and the weft).

In this research the additional restriction of working with predetermined, unalterable warps, meant that 'active' yarns (Section 4.6.5) were confined to use in the weft. Had they been used in the warp, they would either be continuous throughout selected sections of the fabric/lay-plan or would remain unwoven in sections, thus generating unusable warp waste (see below).

This research, therefore, makes a significant contribution to the existing body of research into fully-fashioned, single-piece and composite garment weaving, by specifically focussing on the elimination of waste, addressed for the first time, through the synthesis of textile and garment construction in the form of zero waste lay-plans. Thus, establishing an original approach (CPW) to the integration of integral shaping of woven fabrics and assimilation of multiple textile qualities within garment patterns using hand, hybrid and digital modes of construction. Furthermore, the research explicitly identifies a number of complexities associated with garment composite and fully-fashion garment weaving and establishes the limitations of integrally shaping woven textiles due to the inherent characteristics of their construction (i.e. the use of a warp of continuous width held under tension, and the interlacement of multiple sets of threads).

Sustainability: the unique characteristics of CPW, through its simultaneous design and production of textile and garment, lends itself to the integration of sustainable design principles and strategies such as zero waste pattern/garment design, as decisions relating to fabric composition and garment styling that are intrinsic to the sustainable production, use and disposal of clothing, are addressed at the design stage. It necessitates the assimilation of process stages that Rissanen and McQuillan (2016) and Gwilt (2011), amongst others, suggest can contribute to a more sustainable fashion system. Through the implementation of defined sustainable design principles (Section 5.3), this research demonstrates the sustainable potential and challenges for composite pattern and garment weaving by:

- Eliminating cutting waste through the adoption of zero waste pattern cutting techniques and extending its capabilities through the introduction of multiple textile qualities and compositions within a single length of fabric.
- Highlighting the issue of inherent warp waste in woven production and establishing methods to minimise and utilise warp waste (i.e. by generating usable warp waste for use as weft yarns and garment insulation/padding); applied on a small scale in this research, these techniques have the scope to be upscaled for industrial production.
- Producing a series of single-piece and multi-piece garments with integral shaping and/or functional panelling that are composed of a single fibre to ensure a 'cradle to cradle' approach (Braungart & McDonough 2009) through suitability for end of product life recycling; recognising and establishing the limitations of mono-materiality for integral shaping, garment functionality and technique reproducibility/predictability through analysis, evaluation and identification of areas for further improvement.

Garments: the construction of garments using different modes of production and forms of construction (single-piece, multi-piece and composite), culminated in garment prototypes of varying levels of complexity. Regardless of their ultimate/individual success or failure, the garment prototypes developed through this research (Chapter 7) facilitated the development and application of multiple techniques and design features (e.g. functional panelling, integral shaping, adjustable gussets, quilting, facings and linings, collars, and gathered cuffs and waistbands).

The shift from developing fully-fashioned composite garments to concentrating on engineered zero waste lay-plans/pattern, combined with my lack of fashion design experience and skills, resulted in the integral shaping techniques developed in the Component Construction phase and the capacity to create curved and contoured garment components being under-utilised. In addition to the findings already described, the following key point was identified during garment construction:

- The construction of complex lay-plans incorporating curves inhibits the ability to make direct interventions in the weaving process to address discrepancies between the intended digitally programmed garment dimensions, as the addition or reduction of picks distorts pattern/garment shape.

8.2.2 Practice: Recommendations and Future Research

The challenges encountered throughout the practice, along with the technical research findings, have considerable implications for the progression and application of composite pattern and garment weaving[1]. However, they do not preclude further technique and process innovation, and the successful development of garments with commercial value and validity, especially if a collaborative approach to design and research is adopted, with fashion and weave specialists working together to fully realise the potential of composite pattern and garment weaving.

Based on the practical findings and technical limitations of this study, the following areas for **continuing development and further research** have been identified:

- Further in-depth and sustained examination of integral textile shaping mechanisms to establish the true potential and limitations of yarn and weave structure manipulation techniques for the fashioning of woven garments; assessing consistency/reproducibility, flexibility and functionality.
- Continued development of seamless composite garment construction; focusing on the minimisation of off-loom construction (i.e. cutting and stitching) and sustainable design potential.
- Further exploration and exploitation of complex lay-plans incorporating curved components and contoured panelling to assess the extent to which CPW can compete with and/or complement existing garment construction and production methods.

[1] They may also, in part, account for the limitations of existing research into single-piece and fully-fashioned garment weaving, and the adoption of integral garment weaving for fashion applications.

Furthermore, the methods developed, and the prototypes produced as part of this research highlight the **following design and process potential** for future investigation:

- Potential for the integration of smart technologies into engineered single-piece and seamless garments; capitalising on the ability to precisely position smart yarns and components and accommodate electronic circuits through seamless construction (Section 4.3.2).
- Scope to develop seamless garment components and composite garments with advanced functionality for specialist (e.g. medical) and performance (e.g. sports) as well as fashion applications; employing innovative body mapping and 3D modelling technologies for the accurate positioning of engineered functional panels to respond to the needs of the body/wearer.
- Opportunities for the integration of decorative engineered patterns within individual garment components to eliminate the need for pattern matching, thus reducing the resultant cutting waste.

In response to the practical findings and outcomes, as well as the challenges encountered and experience gained throughout the research, I propose a number of **practical recommendations for other researchers investigating fully-fashioned, single-piece and composite garment weaving**:

- The use of Jacquard looms with single-end control and a single-harness to offer sufficient flexibility to produce complex lay-plans and maximise garment design possibilities.
- Where possible, to use warps designed specifically for and in conjunction with garments being produced rather than working with predetermined warps; thus, ensuring garment-appropriate fabric density and characteristics when combining double and single cloth construction, as well as facilitating the integration of 'active' fibres to maximise opportunities for integral fabric shaping.

- To undertake cross-disciplinary and collaborative research, whereby individuals (or teams) with advanced knowledge and experience of both woven fabric construction and fashion design, develop garments in tandem to ensure equity of knowledge, skills and experience in order to fully realise the potential of simultaneous textile and garment design and production.

In my own practice I intend to pursue and focus on the following areas of research:

- The resolution of practical issues (relating to accuracy of dimensions and inconsistencies in warp tension) experienced when working with the TC2 loom; working to develop woven design calculations and digitisation methods for use specifically with the TC2 for the efficient production of accurate garment components and lay-plans.
- Investigation of the opportunities for integrating decorative patterns with CPW; considering and developing techniques for positioning and applying repeat and non-repeating patterns in single-piece and multi-piece composite patterns using digital Jacquard looms.
- Continued exploration into the compatibility of yarn, weave structure and lay-plan/garment design combinations through extensive sampling and experimentation using hand and digital looms; working to further establish the capability and limitations of integrating multiple woven structures and fabric qualities within a single piece of cloth.
- Establishing a collaborative partnership(s) with fashion designers specialising in ZWPC; working to advance the CPW system by developing garments of greater complexity to exploit its capacity for seamless construction and assimilation of multiple textile properties and characteristics.
- Initiation of a cross-disciplinary research project, to bring together weavers, engineers and fashion designers, to explore the possibilities and potential of designing and building a new kind for loom for the development and advancement of Composite Garment Weaving.

The CPW system has a wide range of possible applications in the textile and fashion industry. The simultaneous production of textile and garment components, in particular the seamless assimilation of multiple (functional) textile qualities, offers new functional and sustainable design opportunities for fashion and functional clothing (and product) manufacturers. With the potential for the CPW system to be applied, expanded and advanced through the integration of smart technologies and performance fibres, in conjunction with advanced body-mapping technologies, for sports, medical, wellbeing and other specialist performance/functional applications. As such, CPW could facilitate the integration of sustainable design and production strategies alongside technical textile, garment and product innovation.

8.3 Methodology: Reflections, Findings and Further Research

The newly devised Transitional Design Methodology was predicated on the hypothesis that the integration of hand and digital methods through simultaneous (rather than linear) experimentation, design and production enhances innovation opportunities, stimulating and pushing the boundaries of both forms of production. The research and research methods were designed to test this hypothesis; facilitating and encouraging knowledge and skills transfer using hand and digital processes concurrently throughout the design and construction process.

The garment prototypes themselves are the embodiment of the learning and knowledge derived through the application of the Transitional Design Methodology; the evolution and interconnectedness of the garments, along with the documentation of the process of development (i.e. Journal Excerpts and Sketchbook Annotations), are presented as evidence of the methodology's success. The experimental visual format of the thesis, through the inclusion and integration of images and journal excerpts, exposes the nature and rigour of my practice as well as capturing and communicating my thought processes, experiences and learning; further demonstrating the value, significance and potential of the Transitional Design Methodology, as well as emphasising the importance of reflective practice in this study.

The implementation of the iterative transitional approach to hand and digital practice, along with a number of significant incidents, occurrences and experiences encountered during the practice phases of the research, culminated in the following critical findings:

- Planning, preparation based on loom specifications, principles of construction and prior experience are no substitute for time spent getting to know and understand the loom; a relationship with the loom is required to enable the identification and navigation of its behaviours, capabilities, limitations and tolerances in order to develop successful high quality outcomes.
- Working between modes of production not only facilitates the transfer and development of knowledge, skills and ideas, it also enables greater understanding of processes and exposes the hidden potential of the machine(s) - when a process fails on one loom, the perceived limitations of another become an advantage/opportunity.

8.3.1 Methodology: Reflections and Findings

The conscious formal application of the Transitional Design Methodology has not only given greater insights into my own practice and ways of working, it has also confirmed the practical benefits and impacts of working iteratively between hand and digital production to advance practice and design outcomes; providing a new model for the integration of traditional and advanced technologies. Furthermore, it has demonstrated the value, future potential and opportunities for the implementation of the approach alongside existing sustainable design strategies.

Implementation: the formal recognition and implementation of the Transitional Design Methodology, uniquely devised so that technical testing, textile and garment design and production using hand and digital looms all take place simultaneously, resulted in the following:

- Deliberate, conscious and systematic questioning of processes (what they can and can't do) and their potential, taking place when designs are developed on paper and during weaving, and through sample/design analysis and evaluation.

- Purposeful and calculated testing of materials, techniques and machines; pushing their boundaries to establish their limitations, expose and eliminate problems, and find new solutions and ways of working that inform and shape garment design and production.
- A collection of interconnected garment prototypes that share materials, weave structures and the techniques being developed, employing hand, digital and hybrid construction.

Impact: by purposefully and actively working iteratively between hand and digital production, the Transitional Design Methodology has given rise to an innovative collection of interconnected garment prototypes that share materials, weave structures and techniques. They have proven the benefits (listed below) of adopting a transitional approach to design using multiple modes of production to advance personal practice and research outcomes, and demonstrate the advantages of developing interconnected, not independent, garments.

- New materials, techniques, processes and equipment become familiar over time; the knowledge and skills developed through prolonged engagement and repeated use exposes new potential through greater understanding and experience.
- Ideas, techniques and processes are able to develop as they are used in new ways across the collection; opportunities are revealed and problems are solved by working with the varying constraints of multiple modes of production, resulting in a cross-fertilisation and evolution of ideas through experience.
- Technical experimentation, sampling and final garment production, along with the analysis of designs, sparks new creative ideas that can be acted upon and applied without delay in concurrent (or parallel) and subsequent garment designs; capitalising on the ideas that evolve and the problem-solving that occurs during weaving.
- Waste generated in the production of one garment can be integrated into the next; new design ideas are developed in response to and making use of the waste from prior production, creating a physical and visual connection between garments through a cyclical approach to design and production.

Critical Practical Experiences: the introduction and experience of working on the TC2, and most significantly my failure to produce fully successful designs using it, stressed the value and validity of the Transitional Design Methodology. The circumstances surrounding the delayed installation and use of the TC2 meant that hybrid production unexpectedly took place at the very end of the practice period. The garments were, however, designed alongside hand and digital designs and production; responding to sampling and garment outcomes and applying digitisation and calculation methods developed for use on the power loom. Designs were based on and designed to capitalise on the TC2's technical specifications: warp width and density, single-end control, non-repeating warp and manual weft insertion. This, and the unforeseen approach to design, resulted in and identified the following:

- The TC2's technical specifications on paper (theoretically) removing many of the boundaries of other modes of production, resulting in innovative and challenging designs being developed.
- The limitations of the loom being established during the process of weaving garment prototypes, with some issues (but not all) being resolved when designs were produced for a second time.
- The physical production of the garment prototypes revealing that aspects of the innovative designs are (currently) beyond the capabilities of the loom.
- The limitations of the TC2 underlined the advantages of an openness to alternative approaches. For example, the automation of the TC2's warp beam advancement inhibited tension control, highlighting the increased control provided by manual warp winding and adjustment of tension on the hand loom, and the consistency of weft density on the power loom.

Personal Practice Insights: the combined experience of working with an unfamiliar loom (the TC2) and implementing the Transitional Design Methodology for the first time, has provided new insights into my established approach to hand and digital practice, and my development and application of knowledge. It has also challenged my personal perceptions and assumptions about the relationship between the maker and the machine, and the critical points in the design process. Despite being an experienced hand and digital Jacquard weaver, whilst I had recognised the critical importance of both theoretical and experiential knowledge of materials, weave structures and processes when making the transition from hand to digital weaving, I had severely underestimated the importance of 'knowing' and building a relationship with the loom. Through my physical and reflective practice, I have discovered that:

- Whilst it is possible to prepare for and consider the potential of automated and digital production by engaging with hand processes, this does not diminish the need for engaging directly with the loom to establish its limitations and individual idiosyncrasies in order to accommodate and overcome them.
- Digital designs and calculations cannot account for or accommodate the idiosyncrasies of the loom, its automated features and/or the physical realities of material and weave structure combinations.
- The TC2 loom's specifications and apparent capabilities (i.e. freedom of yarn usage, single-end control and non-repeating warp), resulted in a perceived freedom of design through the elimination of the boundaries of other modes of production. In reality it imposed new, unexpected limitations, which were exposed during the process of construction.
- When designing garments for digital power loom and hybrid TC2 production, I considered design calculations and digitisation to be the most critical and influential part of the process, resulting in a partial abdication of manual responsibility and lack of engagement during the weaving process.

This final point was exhibited in the following actions and responses during TC2 production:

- Relying on a single test measurement at the start of weaving to confirm the intended/correct garment dimensions would be achieved.
- Accepting errors that appeared during the weaving process – blaming the loom for the faults rather than attempting to correct them.

Recognising these actions and responses during the process of weaving using the TC2 for the first time, combined with the resultant unsuccessful garment outcome, necessitated a change of approach and a change of mindset, towards increased responsiveness and active engagement with the fabric as it was being constructed. This involved:

- Applying caution through the frequent checking and measuring of the design's accuracy, rather than relying solely on the pre-programmed design (i.e. the correctness of calculations).
- Intervening to address apparent errors in the design by unpicking and re-weaving sections of the fabric and adjusting the digitally programmed design during production to counter dimensional inaccuracies.

The application of a 'hand weaver's approach' when working with the hybrid loom resulted in the production of a more (but not completely) accurate and successful design (i.e. a reduction of discrepancies between the intended digitally programmed design and the physically woven outcome). This identification of my unconscious 'hand weaver's approach' and conversely my 'digital weaver's approach', along with the unintended (and unavoidable) late implementation and use of hybrid production towards the end of the research raises questions about the Transitional Design Methodology and provides opportunities for my future practice (Section 8.3.2).

8.3.2 Methodology: Potential Application and Further Research

The methodological findings from this research, whilst based on the practice of weaving, provide a platform for future implementation, testing and development of the newly established Transitional Design Methodology in the fields of textile and fashion design and beyond. In the context of this research, the methodology has proven to:

- Effectively promote the transfer and development of knowledge, skills and ideas between hand and digital design and production; facilitating the production of innovative designs and the advancement of personal practice.

- Enable greater understanding of processes and expose the hidden potential of traditional hand, advanced digital and automated hybrid equipment/machines; opening up new opportunities for design and production.
- Promote the production of interconnected, rather than independent, design outcomes; enabling the development of skills, knowledge and understanding to facilitate problem-solving and the evolution of ideas through sustained engagement and experience of material, processes and production.

As such the Transitional Design Methodology's integration of hand, digital and hybrid design and production (along with CPW) presents students, educators and designers (independent and in industry) with a new way of approaching textile and fashion design. Whilst this research focuses specifically on the integration of hand, digital and hybrid technologies for textile and fashion design, this iterative approach is applicable to other disciplines and practitioners seeking to employ and integrate advanced technologies with (hand) craft practice. More specifically, my research into the Transitional Design Methodology shows that it offers an alternative to established linear (Section 2.5) and parallel models (Section 3.6) of practice through a holistic, cyclical approach to textile and fashion design, whereby textile and fashion collections are designed to be physically as well as visually connected through the integration of production waste. By fostering a responsive approach to design, this way of working has the potential to deliver the dual benefits of minimising waste and material consumption and stimulating innovative design solutions for the utilisation of waste.

Furthermore, the implementation of the Transitional Design Methodology and the identification of my two distinct approaches to hand and digital weaving (Sections 7.9.4 and 8.3.1; Journal Excerpt 7.10) has raised the following questions for further investigation in my own weaving practice:

- To what extent can the 'hand weaver's approach' be applied to digital power loom production? What are the benefits, impacts and implications of approaching digital production in this way?

- Does the full and immediate integration of the hybrid loom alongside hand and digital Jacquard power looms within my practice further extend opportunities for knowledge, skills transfer and innovation?

Additionally, I am keen to promote and encourage the use/trial of the Transitional Design Methodology amongst my peers, through the dissemination of my research, to allow me to assess the true value and success of this original approach to practice-led research.

8.4 Practice and Methodology: Embracing New Knowledge

As a weave practitioner, researcher and educator I intend to build upon the new knowledge derived through this research, and the development of the Transitional Design Methodology and the Composite Pattern Weaving system in my future practice, with a view to:

- Disseminating my research findings through journals, publications, conferences and exhibitions; continuing to explore alternative experimental approaches to communicating my practice using visual formats.
- Establishing cross-disciplinary relationships with fashion designers and textile technologists, to further investigate and establish the capabilities and potential applications of CPW.
- Initiating a collaborative disciplinary project with weavers, engineers and fashion designers, to explore the viability and potential of building a specialist loom for the advancement of CGW.
- Pursuing collaborative research projects with artisanal weavers to explore opportunities that digital technologies could provide for communities seeking to sustain their unique cultural heritage, following interest in my research from Ixchel Museum in Guatemala.
- Applying methodological and technical insights and approaches to inform the development of my teaching methods and strategies.

By maintaining links with hand weaving traditions and embracing new advanced (digital) technologies, this research affirms the critical importance of the maker's relationship with the machine. Thus, expanding upon the well-established approaches (and thinking) that emphasise the importance of "being led by the material" (Albers 1985 in Margetts 2018: 36) and the relationship between the maker and materials via the tool(s) (or machine(s)). The Transitional Design Methodology contributes a new iterative approach to practice that challenges existing linear approaches to the integration of traditional and advanced technologies. The Transitional Design Methodology has proven to facilitate the transfer and development of knowledge, skills and ideas, to foster a greater understanding of processes and initiate innovation. Furthermore, the research defines a third type of practice – hybrid practice. Hybrid weaving, through its synthesis of 'old and new' processes and technologies, presents new technical challenges (and limitations) for practitioners to overcome. As such, it questions past/future methods of making and offers new opportunities of innovative practice.

The Composite Pattern Weaving system (in conjunction with the Transitional Design Methodology), through the integration of hand, digital and hybrid textile and fashion design processes, and the simultaneous production of textile and garment components (in the form of zero waste lay-plans), contributes a new approach to practice that supports a 'less is more' model of production and consumption. In doing so, the research responds to the need for "new sustainable frameworks for fashion", that question the continuing growth of textile and fashion production and resource consumption (Global Fashion Conference 2018); presenting a mode of design and production that facilitates the integration of multiple sustainable design strategies which emphasise garment functionality, durability and longevity, as well as the minimisation of material consumption and waste throughout the garment lifecycle.

8.5 References

BRAUNGART, M. & McDONOUGH, W. (2009). *Cradle to Cradle: Remaking the Way We Make Things*. London: Vintage.

GLOBAL FASHION CONFERENCE. 2018. ' What's Going On? A Discourse on Fashion, Design and Sustainability Programme'. *Global Fashion Conference*. Available at: http://gfc-conference.eu/wp-content/uploads/2018/10/GF2018_PROGRAMME-FINAL.pdf. Available at: http://gfc-conference.eu/wp-content/uploads/2018/10/GF2018_PROGRAMME-FINAL.pdf. Accessed: 08 November 2018.

GWILT, A. (2011). 'Make - Producing Sustainable Fashion'. In: GWILT, A. & RISSANEN, T. (Eds.). (2011). *Shaping Sustainable Textiles: Changing the Way we Make and Use Clothes*. London: Earthscan. pp. 59-73.

MARGETTS, M. (2018). 'The Growing is the Thing'. *Crafts Magazine*. No. 274. Sept/Oct 2018. pp. 36-44.

RISSANEN, T. & MCQUILLAN, H. (2016). *Zero Waste Fashion Design*. London: Bloomsbury.

Appendices

Appendix 1

Design Reviews

Component Construction: Design Review & Development – 3D Folded Structures

Reflections

- **Moves:** Reflection on action taken > What has been done so far? What are the individual problems?
- **Consequences:** Reflection on problems to establish alternative solutions > What are the unintended consequences (positive and negatives)? How can they be resolved or developed?
- **Implications:** Reflection on the suggested solutions > What are the direct implications for the current design, the fabric, the process etc.?
- **Appreciations:** Reflection on the wider impacts > What is the impact of these solutions on the wider design/concept? E.g. sustainability, application to garment, transition to or from the digital
- **Further Moves:** Application of ideas and new thinking based on reflections > What is the next step/action? Do I accept the impacts elsewhere?

	Moves >	Consequences >	Implications >	Appreciations >	Further Moves >
Stage #1	Folding technique (based on corded pleat principles) tested on the hand loom using a diamond pattern, a 27 Tex Polyester Warp & base cloth, and Shrink Polyester & High Twist Wool 'active' yarns. Shrink Polyester Sample: the polyester has shrunk drawing together the cloth where the floats are positioned, resulting in a raised relief pattern. The base cloth has not responded to/been manipulated by the shrinking. High Twist Wool Sample: the floats have not been reduced in size, although there has been some textural relief generated. The 'activity' in the wool is almost zero and so is not sufficient to manipulate or shape the cloth.  Sample using 60/2 Polyester Shrink as Active Yarn	The Polyester base cloth is light/limp, providing little resistance for the 'active yarn' to work against – rather than being forced to create form, the Polyester has simply moved and distorted within the structure. A stiffer/more resistant yarn used in the base cloth weft may provide the desired manipulation and structural effect. In comparison to the plain weave only samples using High Twist Wool, the movement/activity has been diminished. It seems unlikely that this is solely due to the base cloth (as described above), as the plain weave sample was also composed for High Twist Wool and Polyester. The two variables were – the weave structure, and the ratio of High Twist yarn in the weft. Using 100% High Twist Wool in the weft may provide more 'activity' and 'power' to shape the cloth. However, this may result in disruption of the surface of the base cloth, rather than focusing the 'activity' in the floated sections. Another option would be to replace this Wool with a thicker more 'powerful' one (based on findings from technical sampling. Alternatively, the yarn may require more space to move and 'activate', a longer float (greater than 2 ends) could be used (this may also apply to the Shrink Polyester sample). This would impact on the overall scale of the pattern (and its folding) due to shaft limitations – the design is already being tested at a very small scale due to these limitations. Using the Jacquard rather than the hand loom would give more flexibility in pattern scale.	The use of a stiffer/more resistant yarn may have a negative impact on the handle of the cloth – making it rough to the touch. However, a balance should be possible. A further selection of different types of yarns needs to be explored, to find a fabric composition that is functional both for wear and to create the desired 3D effect. Texts describing corded pleat shaping techniques using 'active' yarns, suggest a mix of 'active' and 'passive' weft yarns, with a base cloth created using the 'passive' yarn and using 'active' yarns in the floating picks to create the folding. By using an 'active' yarn throughout there is a risk of disrupting the whole cloth (creating tracking, gathering and instability) rather than shaping it in selected places. Although shaping may be achieved the appearance of the cloth could also be negatively affected. This could be tested on the next pleating warp using an alternative lifting plan. Using thicker and more 'powerful' wool with the Polyester currently in use would result in a heavier cloth and potentially an unusual appearance. This could be countered by using a different Polyester or base yarn, and/or ensuring the two types of yarn are the same colour to limit the visual inconsistency. There is the possibility that this could create an interesting effect. The small scale of the pattern was a concern before undertaking the sampling, reducing it further would (if 3D form is successfully achieved) create an aesthetic rather than functional shaping effect. Moving testing and construction of this fabric design/type to the Jacquard removes these scale restrictions, but places limitations on yarn usage – the warp yarn will have to be combed cotton.	For sustainability reasons (recycling possibilities) single fibre fabrics are the ideal. Moving the development of this fabric type to the Jacquard loom, means that in sampling at least, this will not be possible – as the effective 'active' yarns identified in the first batch of samples are not cotton based. The Jacquard loom also places restrictions on the weft yarns that can be used. Testing of yarns will need to be undertaken to establish which 'active' yarns are compatible with the loom and its set-up. This is something that would have to take place at some point in the fabric and garment development process anyway. The complexity of the lifting plans required for the folding fabrics (and the associated shaft requirements), means that fabrics of this type could only be integrated into garments on the Jacquard loom. As such, it makes sense to develop the basic fabrics in this format, rather than adapting and re-designing fabrics produced on the hand loom for digital production. The speed of production on the Jacquard loom means that a range of tests (of yarns, pattern scales, weave structures and patterns) will be increased on the Jacquard loom – subject to loom access and availability.	1. Move the development of these fabrics from the hand loom to the Jacquard loom. 2. Undertake yarn testing on the Jacquard loom to establish which 'active' yarns are compatible with the process. 3. Source and test alternative base fabric weft yarns – looking for stiffer more resistant yarns that are also suited to a fashion application. 4. Increase length of the floats in structures from 2 ends to 4 ends in new designs to establish if this results in more effective folding and yarn shrink/movement. The use of multiple fibre types, and the imposition of a cotton warp is something which would have happened at the point of transition from hand to digital production, no matter when this takes place in the development process. If production is outsourced later in the research, this issue could be addressed. Hand weaving and sampling (that will continue for the development of other fabric types and garments), will inform warp choices should outsourcing take place.

	Moves >	Consequences >	Implications >	Appreciations >	Further Moves >
Stage #2	Multiple V pattern (based on paper folding technique) tested on the Jacquard using 52/2 high twist wool and 32/2 combed cotton in the weft. Based on findings from stage 1 floats were increased to 4 ends. Greater movement was achieved in the floated sections, but the longer floats have resulted in the wool looping on the surface of the cloth rather than pulling the cloth together. Due to changing structures within the pattern, there are some instances where 2 end floats occurred accidentally – these have resulted in a stronger pull and movement in the cloth. The combination of wool and combed cotton in the base cloth has resulted in a lightweight and well draping cloth. Whilst some forwards and backwards movement has been achieved in the base cloth the fabric still seems to be too limp to fold any sort of structure or form.	Although this is contrary to previous findings, this sample suggests that a shorter float has a greater force and manipulating effect. As such the floats will be reduced to 2 ends in future samples. The lightness and limpness of the base cloth was identified as an issue in stage 1, and the yarn combination used in stage 2 has not improved the fabric weight. As the density of the Jacquard warp or the yarn cannot be altered to contribute towards a stiffer cloth a thicker or stiffer passive yarn is needed in the weft. Wool has been used in the base cloth of other technical samples and has resulted in a slightly stiffer and thicker cloth. There is then potential for felting the base cloth to add further stiffness. Decision: combine the active 52/2 high twist wool with a passive wool in the base cloth. Having, at this stage, only produced a single sample with a 1" design motif it is not possible to assess the impact of the pattern scale on creation of 3D form and folding. Decision: solutions and developments identified here will be applied to both a 1" and a 2" motif to allow the impact of the scale to be accessed.	If the folds are created using a 2 end float, this could limit the structures that can be used in the base cloth, as anything other than a plain weave would have an equal or larger float meaning that the activity of the high twist wool would not be focused/confined to the folding/floating sections. This could have an impact on two things: 1. Felting of wool yarns has been shown (in other samples) to inhibit felting of wool. 2. Aesthetic/decorative effects would be limited to weft stripes. Felting may or may not be required in order to achieve the appropriate weight of cloth – it may be possible to use a longer float structure only in the passive yarn picks to expose more of the yarn fibres to encourage felting. The same approach could be utilised for aesthetic purposes. However, there is scope to create effective aesthetic appeal using colour variation and plain weave. There is potential for a stiffer base cloth resulting in increased bulk and perhaps some roughness. Additionally, the Jacquard will place limitations on the thickness of yarn that can be used. In the first instance wools tested in other samples will be tested – the main aim at this stage is to achieve the 3D form.	Issues with bulk and roughness can be addressed and resolved once the desired effect is achieved. It is perfectly possible and acceptable that the fabric (its handle, weight, appearance etc.) will drive/influence the type of garment component it is applied to. As outlined previously for sustainability reasons a single fibre fabric is desirable. This is not possible due to the cotton warp on the Jacquard loom. If this becomes a crucial issue in the research, prototype garments could be supported by a collection of hand-woven samples using a single fibre type to demonstrate the fabric composition options i.e. to show that it would be possible to reproduce the prototype in a single fibre.	1. Reduce float length to 2 ends in an attempt to reduce surface looping and increase fabric movement. Continue developments with a plain weave base cloth – alternative structures can be tested once 3D form and folding has been achieved. 2. Combine the active 52/2 high twist wool with passive wools (already tested in other samples) to increase the stiffness of the base cloth. 3. Further yarn tests to be applied to two scales of motif (1" and 2") to access the impact of scale on the creation of 3D form and folding. 4. Concentrate on 3D folding structures in order to make timely progress – then apply findings to the production of corded pleats.
Stage #3	Multiple V Pleat and Translation Motif tested on the Jacquard at varying scales using 27Tex Polyester weft and extra weft for Shibori gathering. Both patterns were applied to single cloth (48 EPI) and double cloth (96 EPI) construction. Float placement and scale was effectively achieved following a number of tests, however, a flaw remains in the base cloth at the point of repeat. Two samples (one single and one double cloth) were gathered and partially finished using the iron. The process is time consuming and largely unsuccessful. Single cloth: folds are ill defined particularly at the point of transition between mountain and valley fold. An irregular twisted pleat rather than 3D form has been achieved. The light nature of the cloth means that the pleats are easily flattened.	The single cloth is limp with little supportive ability. The double cloth is more able to support a structure, but the folds are rounded rather than sharp. A balance between the two could be more effective. Alternatively, an increased PPI in the single cloth construction could provide a denser firmer cloth. Although the Shibori texts suggest that polyester in the weft only is sufficient for horizontal folding, it may be that given the complexity of these folds, a polyester warp could result in a sharper and crisper pleat. Floats of 4 ends have been used to form the gathers and pleating. When gathered, despite the application of pressure the folds and structure remained quite loose. Reducing the number of ends could result in a tight gather and a sharper fold. The gathering process is very time consuming due to the number of float threads required to manipulate the cloth. As at this stage the folds are not sharp or defined enough reducing the number of gather threads seems to be inappropriate. The time-	The current Jacquard set-up does not allow for a change of EPI and the PPI currently used is the maximum possible with the structures and yarns selected. However, the TC2 will facilitate these changes. Again, it is not possible to alter the existing warp on the Jacquard loom, but this could be an option on the TC2. A number of variables have been identified that could impact on the success of the folding technique – density, float length and fabric composition. Until the TC2 arrives, these variables and the potential of the technique could be explored through fabric manipulation and stitching. Base fabrics could be produced on the hand loom to specifically test and experiment with the yarns that would be used in woven production. In addition to the above, it could also be beneficial to test the technique on the Jacquard loom and by hand with simpler 3D forms, to gain greater insight into the process and the impacts of the various components. Simpler pleats could be explored – as pleats have been achieved on the hand-loom, shaped pleats could be worked with on the Jacquard to extend the potential	The arrival of the TC2 will impact on the development of this particular technique. As such there is a risk of running out of development time. Using fabric manipulation and stitching to assess the techniques potential could alleviate this and allow judgments to be made about the value and viability of the process. However, it is important that other avenues for Jacquard development continue to be explored to balance this risk – development will therefore concentrate on the shaping capabilities of waffle structures. The introduction of the TC2 and the flexibility it provides for yarn usage (particularly in the warp) has significant benefits for sustainability, as there is more scope for producing 3D folding fabrics using a single fibre. Testing the process using fabric manipulation techniques will be time consuming but can be done away from the loom and so access issues will be alleviated. Base fabrics can be produced on the hand loom as part of hand weaving development. This could give greater scope for testing a range of yarns and compositions, which could serve to demonstrate	1. Experiment with fabric manipulation and stitching to develop the technique and establish the requirements for weaving. 2. Alongside hand weaving for the development of other techniques produce plain base fabrics for fabric manipulation, to assess the suitability of fibres and yarns. 3. Prioritise the development of waffle structures on the Jacquard. 4. Using the existing Jacquard set-up, test simpler structures/patterns i.e. pleats and shaped pleating. 5. Based on the above, make a decision about the viability of the technique for shaping garment components.

	Moves >	Consequences >	Implications >	Appreciations >	Further Moves >
Stage #3	Double cloth: again, the folds are ill defined as above. However, the cloth is more substantial and is better able to support and hold structure/form.	consuming nature of the process leads to questions of viability technique for shaping garments that are intended to be 'wearable from the loom'.	application of pleating within the garments, and to (whilst simplifying the construction) still capitalise on the Jacquard's single-end control. The time-consuming gathering of the yarns is an inevitable part of the process and cannot really be overcome. Restricting the use of the technique in a garment component could limit the impact.	greater technique flexibility. Ultimately a decision needs to be made about the viability of this technique. This is very much dependent on the success of testing outcomes, as the technique could provide a very different type of shaping and fitting than the other techniques currently under development. At this stage development will continue but this will be secondary to the development of other techniques.	

Component Construction: Design Review & Development – Panelled Fabrics (Clasped Weft)

	Moves >	Consequences >	Implications >	Appreciations >	Further Moves >
Stage #1	Basic catching-in method developed and applied to a single triangular shaped panel. The intention was to create a stiff panel and soft draping base cloth. • 2/16 Mercerised cotton (base) & bundle 60/2 silk (panel): effective panel shaping, but little contrast in handle. • 27 Tex polyester (single & bundled): as above. Base cloth has very soft, light and smooth handle. • 2/16 Mercerised cotton (base) & bundle 9.2/nm linen (panel); contrast between the two panel, with linen inhibiting drape. Both cotton and linen result in a rough cloth. • 2/16 Mercerised cotton (base) & bundle 2/21nm wool (panel): as above. Soft spongy panel The linen provided the best level of contrast to focus and control the drape of the cloth. However, it raised questions about the wearability of rigid cloth. The single panel did not provide an indication of the potential of a hinging effect in the cloth – multiple panels would be required to do this. The technique was effective, but samples were slow to construct. In these cases, there was no set plan or dimensions for the panels.	Softening the handle of the lighter cloth rather than increasing the rigidity of the heavy cloth could increase the contrast between the two weights of cloth. The 27 Tex polyester when used in warp and weft provides a much lighter cloth than the cotton warp, and so could be suited to this purpose. Fine wool could also be utilised and combined with a felting wool panel. Increasing the number of panels in the fabric needs to be tested in order to access the hinging capabilities of the cloth. This will increase the complexity of construction and will require significant planning of panel placement. The silk due to its soft handle is not suited to the creation of contrasting weight panels and so should be eliminated from this particular design development. However, it could be effectively applied in other panelled fabrics and garments. There is potential for utilising the differing weights of cloth to focus and place sections of manipulated (pleated, gathered, shrinking etc.) fabric for the purpose of facilitating movement or shaping (also see pleated fabric review) – using heavy panels to inhibit the movement of the active yarns.	The combination of two weights within a single cloth using the catching-in technique, presents possibilities for complex panelling and combining active and passive yarns to create shaping effects as well as facilitating movement (as described). Although some yarns have been identified as being successful and worthy of further development, they require further testing in combination with this new development – this applies to the yarns that have been identified in catching-in sampling but also yarns that have been deemed successful in pleating and shaping. The catching-in/panelling technique as a means for creating shaped panels has been successful in a very simple form (although the process of construction itself is quite complex). This now needs to be explored and developed to produce more complex shaped panels – this will require the development of methods to place and calculate the shaping of the panels. Note: methods of calculating shaping used in knitwear have been identified. As the intention is to create fabrics that will map and respond to the body, the above will need to be supported by a greater level of design work and planning to explore and understand the movements of the body to allow appropriate panelling to be developed (both in terms of shaping and positioning, as well as technical construction calculations). This signals a move from test sampling to prototyping.	This method and the ideas developed in response to initial sampling provide new possibilities and options for hand woven construction. A partial weft insertion and the crossing of wefts at points in the cloth is not possible on the digital Jacquard loom, meaning that the specific technique is not transferrable. However, the single end control of the Jacquard does facilitate complex panelling, and structure combinations rather than yarn combinations can be applied to inhibit or accentuate movement/shaping. As such the shaping calculations and the development of panel shapes and positioning are transferrable across the two modes of production. This means that two very different types of garment/fabric could be produced based on a shared process of design development. The yarns selected – polyester and wool – as being most suitable for development provide potential for the development of fabrics/garments/components that are constructed from a single fibre, as both active and passive versions of yarn composed of each of the fibres are available. Additionally, the fact that one of the yarns is natural and the other synthetic provides the opportunity to demonstrate and explore the sustainability and functionality of both.	1. Eliminate unsuccessful yarn combinations from further testing – focus on wools and polyester for the production of wearable/functional fabrics. 2. Apply and develop the catching-in technique to multiple panels within a single fabric – assess the implications for complexity of construction and for hinging effectiveness 3. Undertake tests to explore the impact of panelling (particularly heavy and light weight fabrics) on the activity of yarns previously used effectively to shape and manipulate. 4. Adapt and develop a method of calculating panel shaping using the method utilised in knitwear. 5. Undertake visual research and design development to understand and establish the relationship between the movements of the body and the shape and positioning of panels. 6. Bring together all of the above to develop an initial prototype that combines complex panelling with active and passive yarn shaping – produce a prototype that is aesthetically effective as well as technically effective.

	Moves >	Consequences >	Implications >	Appreciations >	Further Moves >
Stage #2	A small test combining two heavier weight side panels and a fine central panel using an active yarn (Japanese High Twist) in plain weave has been produced. The combination has inhibited the movement of the active yarn. Although the catching-in technique has been successful in holding and connecting the panels, the contrast between the two wefts raises concerns about the weakness of the fine wool.	The central panel was small, this combined with the heavier weight panels appears to have inhibited movement. Increasing the size of the central panel should provide more space and power to move and manipulate the cloth. Although plain weave combined with the high twist wool has previously resulted in pleating, using a combination of warp and weft facing structures has enhanced the effect. Applying this type of structure should also encourage movement. It may be possible to panel the two weights of weft by ensuring that they both cross the same warp end rather than catching them together. This would mean that the warp would provide additional strength and support, rather relying on the fine wool to hold and secure the panels.	Altering and alternating the structure in the central panel, particularly if the panelling is to be shaped, will impact on the weave structure in the heavier panels as the warp will need to be threaded to allow application of blocks of alternate structures to the widest point of the active panel. Past experience suggests that the use of bundled yarns with floated structures is ineffective as the individual yarns are exposed rather than being held and compacted by the regular intersections with the warp. As such plain weave needs to be applied to these sections. This could be achieved by using a lifting plan that alternates between plain weave and the twill repeat, allowing for the bundled yarns to be inserted on one pick and the active yarn being inserted on the next. This may impact on the process of catching-in, but crossing warp ends as previously described would eliminate this complication.	In order to achieve warp and weft facing structures, a minimum of 8 shafts (4 for each block) will be required. This does not present a problem if the shaping of the garment/component is to be achieved with catching-in and cutting ends. However, shaping using a sectional/block warp would be inhibited.	1. Undertake further tests to increase the size of the active panel. 2. Introduce block threading to allow for warp and weft facing structures to be used in conjunction with the active yarn to encourage movement.
Stage #3	A number of waffle structures using various float lengths have been produced on the Jacquard using a combination of 32/3 combed cotton in the warp and 27 Tex polyester in the weft. The structures were being tested for functional application i.e. use in thermoregulation based on their cellular structure. However, an unexpected outcome – significant height reduction (following finishing) in the size of the sample – has been achieved and has potential for application for shaping and fitting garment components. Note: in these samples size reduction was only achieved in the warp direction.	This size change could be capitalized upon for shaping panels, by applying the structures to contoured panel and utilising a more 'active' yarn in both the warp and the weft. This could be applicable to hand and jacquard production. It extends the possibilities of jacquard shaping, meaning that some controlled shaping could be achieved in both the warp and weft direction. A range of float lengths have been tested, with the level of size reduction and stretch in the fabric increasing with the length of float, as such, it may be possible to grade and control shrinkage and stretch by grading the size of float in a particular panel or across a garment component.	The waffle structures require pointed threading and a significant number of shafts being allocated to them. In the case of hand weaving this could present limitations for garment shaping i.e. the silhouette of the garment – sleeves, pockets etc. This could be overcome in the case of garments and components using catching-in and cutting ends.	The reduction of size is accompanied by an increase in bulk in the fabric, as the cells become deeper. This may place some limitations on the positioning of the structure within a garment (or component) e.g. it may not be suited to under arms. It will also impact on the weight of the garment, and so may be suited to outer and mid-layer garments.	1. Undertake further tests on the Jacquard using a cotton weft to assess the potential for warp and weft shaping. 2. Undertake shaped panel tests to explore the possibility of controlled shaping through both grading of structures and shape of panel. 3. Test waffle structures on the hand-loom using alternative warp yarns to assess 'activity' – polyester and wool – in preparation for application on the TC2. 4. Conduct further research into functional application and properties of the waffle cellular structure – test samples to confirm/select most functional combinations in terms for thermoregulation.

	Moves >	Consequences >	Implications >	Appreciations >	Further Moves >
Stage #1	Successful and effective 'active' yarns from Warp #1 Testing have been tested on polyester and linen blanket warp, using corded pleat structures (box pleat and knife pleat). Each 'active' yarn has been tested with three base-cloth weft yarns, with different stiffness levels/handles – polyester, Mercerised cotton and linen. The two warp types and three base-cloth wefts used with the intention of assessing the impact of different yarn combinations on the effectiveness of the 'active' yarn movement and the quality of the pleating. Shrink polyester: effective pleating achieved with all yarn combinations. However, the fabrics do not self-fold, they require pressing to full form the pleats. The linen weft results in an exceptionally rough handle, which is unusable. Japanese high twist wool: limited or no movement/yarn 'activity', with no forming or folding achieved. High twist merino: the wool is on the verge of felting, with the wool shrinking the entire width of the cloth significantly, with the exception of the polyester warp & weft combination where 'activity' is focused in the floats resulting in pleating (again they require pressing). Lycra: effective pleating achieved with all yarn combinations, although the base cloth has been disrupted by the shrink effect. A self-fold effect was created through steaming and pressing with paddle on the steam bed – no pressing required.	Yarns & Selection • Linen warp: snaps excessively making weaving difficult and impacting negatively on the quality of the cloth. This generates a lot of warp waste. Fortunately, the pleating effect was no better on the linen warp than the polyester. Decision: no further development with linen warp • High twist Japanese wool: 'activity has been blocked in combination with cord pleat structure. This particular yarn is not suited to this effect but has been successful elsewhere (gathering and shaping). Decision: continue development with this yarn elsewhere but not with pleating – focus on other wools (52/2 wool) for pleating & folding. Surface disruption: in a number of the samples surface disruption of the base cloth has been an unintended consequence. Slight disruption can be managed through pressing and finishing. It may be possible to eliminate this disruption by increasing the density of the warp to limit/eliminate the movement of the yarns in the panels of the pleats. In the case of the Lycra and polyester combination the surface disruption creates an aesthetically pleasing bubble effect in the cloth that could be capitalised upon in sample and garment development. Pressing requirements: all samples (except Lycra) need some pressing to fully form the pleats. Once pressed the pleats generally spring back to their pleated state when extension pressure is removed. If possible, no pressing would be desirable - this may be possible in samples and fabrics of a much larger scale as the power of the movement should be greater and more consistent (texts including Richards suggest that a minimum of 12 inches is required for the best effect to be created).	Increasing warp density • Could result in a heavier and bulkier cloth, however, the fabrics achieved at this stage are relatively light and un-bulky so an increase in bulk may not be detrimental. • May result in firmer and more compact fabrics, this has the potential to improve the shape and permanence of the pleats. This is something that could also be applied to more complex folding fabrics to improve structure and form. Pressing requirements It is likely that the pleating technique will be applied to garments and fabrics on a much larger scale than the samples currently tested and so the requirement for pressing in these cases may or may not be removed. There may be occasions with some garments where very small amounts of pleating or folding are required to facilitate movement, to provide effective articulation or comfort. If self-folding/no pressing is not achieved, this means that garments will not be truly 'wearable from the loom'. In all cases, the 'active' yarns will require some washing and finishing – this is to be expected with all fabrics and garments. However, if washing a garment results in a significant amount of complex pressing, this would be problematic for the usability of the fabric/garment for the consumer. The level of acceptable intervention and finishing needs to be established. At this stage pleating has been applied to the full cloth, rather than applied to particular sections. If a pleat is adjacent to a non-pleated section, will this diminish or flatten the pleat?	It would be possible to combine pleating with more complex garment designs on the Jacquard loom – including selected panelling of pleats. The Jacquard loom also presents opportunities for creating more complex pleats e.g. zigzag or curved. The set nature of the Jacquard warp means that increasing density to reduce fabric disruption is not possible – it is important to note that the density of the Jacquard warp is greater than in any of these samples (96 EPI single cloth, 48 EPI double cloth). The Jacquard loom also places restrictions on the weft yarns that can be used. Testing of yarns will need to be undertaken to establish which 'active' yarns are compatible with the loom and its set-up. Additionally, due to the standardised warp set up, any pleating effects achieved through changing the yarn thickness may not be transferrable to this type of production – although it may be possible to simulate yarn bundling by lifting and lowering a number of consecutive yarns in the same way. The testing of 'active' yarns with multiple weft and warp types means that in many cases fabrics are constructed in multiple fibre types which inhibits recycling. However, as three different types of active yarn have been particularly successful – Lycra, 52/2 wool and shrink polyester – there is still potential for creating a pleated mono-fibre fabric which will be fully recyclable. This would not be the case for Lycra. The different effects achieved with wools (in other test sampling) also indicate that it would be possible to create garments and fabrics entirely from wool that employ different shaping effects.	1. Eliminate unsuccessful yarn combinations from further testing – focus on Lycra, 52/2 wool and shrink polyester, 2. Test successful structure and yarn combination on larger fabrics, and combine pleating and non-pleating sections. 3. Undertake tests to explore the impact of altering the density of the cloth. 4. Undertake tests using thicker/bundled yarns rather than threading plan to create pleated effects. 1. Undertake yarn and structure testing on the Jacquard loom to establish which 'active' yarns are compatible with the process. (also see 3D folded structure development). 2. Test successful pleating 'active' yarn combinations with complex 3D folding techniques – do this in combination with increased density (increased density may create a stiffer form/structure). 3. When undertaking further yarn testing, consider aesthetic appearance alongside to speed up fabric development process. 4. Establish an acceptable level of intervention and finishing based on testing detailed above.

	Moves >	Consequences >	Implications >	Appreciations >	Further Moves >
Stage #1	52/2 high twist wool: effective pleating (neat, good 3D structure) achieved with polyester and cotton weft combinations only. The fabrics are not entirely self-fold and require pressing. Elastomer: 'activity' is totally uncontrolled, shrinking the full cloth significantly and leaving a very rough handle. Note: the three best effects have been created with 52/2 high twist wool, Lycra and shrink polyester. They have created the strongest but different types of pleat – Lycra gives texture and stretch, shrink polyester gives sharp, flat and consistent pleating, 52/2 wool gives a thick neat pleat with body and bounce.	Shaft Allocation & Threading The pleating effect requires a very specific threading plan, using a minimum of 8 shafts. This is not problematic when creating a flat cloth but is restricting for application to hand woven garments as the shaping of the garment silhouette also requires varying amounts of shafts (depending on the complexity of the garment shape). To pleat the fabric a float above or below the base cloth (depending on the direction of fold required) is needed. Using a very thick or a bundle of yarn in the warp would increase the length of float in the warp direction. As such yarn thickness rather than threading plan could be utilised to form the folds. The stiffness of thicker or bundled yarns may also add body and structure to the pleated fabric.	Alternative pleat techniques (shaft reduction) If an alternative method of creating the floats required to pleat the cloth is not achieved, garment styling options on the hand loom will be significantly inhibited. Pleating has two functions – controlling fullness and facilitating movement. It may be possible to apply seersucker effects to facilitate movement, as in the warp, this is not reliant on shaft allocation but warp tension variations. To control fullness gathering and shrinking effects could present an alternative – this would result in a very different garment and fabric aesthetic.	 Bubble Effect/Surface Disruption of Lycra and Polyester Weft Knife Pleat	 Knife Pleat Using 52/2 Wool and 2/16 Cotton Weft Yarns
Stage #2	Alternative pleat technique: placing thick warp ends (of bundled yarns) in the warp to form floats, with active yarns placed to form floats at one side of the thick warp end (front and back alternatively across the warp). The intention was to replicate the folding effect of the corded pleat whilst reducing the shafts required. Weft yarns: the three yarns identified in the last stage – 52/2 wool, Lycra and shrink polyester – have been applied to the alternative pleat technique. Two types of thick warp ends were used – 60/2 Silk & 9.6/2nm linen. 52/2 wool & cotton: no movement or manipulation achieved (with either linen or silk), with the exception of a small amount of tracking in the base cloth. Lycra & cotton: a minimal amount of movement achieved pushing the thicker warp ends forwards and backwards – this is not significant enough to have an effect on the base cloth. A small amount of irregular bubbling (or surface disruption) in the base cloth.	Structure: as the fabric is constructed in plain weave to place the floats of active yarn on one side of the thicker warp end, and to limit disruption of the base cloth the active to passive yarn ratio was 1:3. In the corded pleat structure the ratio is 2:2. This suggests that there was not enough strength in the active yarns to manipulate the floats and form the pleats. The active yarn ratio could be increased to 2:2. Bubbling & surface disruption: in the samples where the activity of the yarn hasn't been entirely blocked – Lycra and shrink polyester – surface disruption (or bubbling) has occurred. In the Lycra sample effect it is irregular and inconsistent, however, in the polyester it is more substantial and consistent. It has an appealing decorative (rather than functional) effect, however the fabric width does decrease and has shaping application possibilities. It is unclear if the effect is due to the cotton/polyester combination or if the thicker ends have an impact. There has been some movement of the thicker ends when Lycra and shrink polyester is used – forwards and backwards movement rather than self-fold. Pleats could be encouraged with pressing however, there is a risk of pressing out the pleasing bubbled effect.	Increasing active/passive yarn ratio: this would impact on the stability of the cloth, and is likely to increase surface disruption, as the active yarn would be incorporate on the same pick of every pattern repeat – there would be no passive base cloth to balance the activity. Pressing: it is highly likely that pressing will press-out the bubbled effect. This could be tested on one of the samples to assess any remaining potential of the technique for pleating. In the last stage I questioned the suitability of fabrics that require pressing to form pleats – as these samples have a lower level of manipulation than the corded pleats (and therefore would definitely require pressing), the technique can be reasonably deemed unsuccessful. The corded pleat is more effective, and efforts should be concentrated on developing them further. Bubbled appearance: the bubble effect is decorative rather than functional, but it occurs along with a 6-14% reduction in width (depending on active yarn) which could be utilised in mild shaping/fitting. The permanence of the effect has been questioned (above) and this needs to be accessed – the effect could, in a garment, reduce the need for ironing (advantageous in the use phase) if it is retained during washing. It is unclear if the bubbling has occurred due to the cotton warp/weft combined with the active yarn or if the thicker warp ends have an impact. If this visual effect is to be capitalised upon this needs to be understood.	As outlined in the previous stage, the corded pleat requires specific threading and significant shaft allocation that limits garment styling options on the hand loom. Given a recent decision to concentrate on components rather than full garments, some of this issue is alleviated. Additionally, the threading requirements don't preclude the use of other structures and techniques and so there is potential to combine pleat with other techniques being developed. As such the corded pleat technique will be developed in favour of the alternative pleat technique. Additionally, the corded pleat technique is (dependent on yarn choice) transferable to the Jacquard, and so more complex pleated garment components could also be developed on the power-loom. It is however important to note that weft-ways pleating only could be applied to the Jacquard (due to restriction on replacing warp yarns). The bubbling effect has been achieved in fabrics that include multiple fibre types. For sustainability reasons it would be preferable to have mono fibre fabrics. Can the same effect be achieved using 100% polyester? This can be established when the effect is better understood. However, as mentioned previously the bubbling effect, if permanent, could reduce laundering requirements that has the potential to make the use phase of the fabric/garment more sustainable.	1. Test permanence of bubbling effect through laundering and pressing samples. 2. Establish the reason for the bubbling effect through further testing of yarn combinations – exploring the possibility of a mono-fibre fabric creating the same effect. Focus on the development of corded pleats rather than the alternative pleat technique – continuing with moves identified in stage 1.

<table>
<tr><th></th><th>Moves ></th><th>Consequences ></th><th>Implications ></th><th>Appreciations ></th><th>Further Moves ></th></tr>
<tr><td>Stage #2</td><td>Shrink Polyester & cotton: a small amount of movement pushing the thicker warp ends forwards and backwards – not significant enough to impact on base cloth panels. A consistent bubbling effect (or surface disruption) in the base cloth.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Stage #3</td><td>Warp & weft facing pleating: combining warp and weft facing structures (1/3 and 3/1 twill) using a block draft with active yarns to create pleats and ridges. The intention is that the floats in the weft facing structure manipulate the fabrics into a valley fold and the warp facing structure forms a mountain fold.

Weft yarns: the three yarns identified in the last stage – 52/2 wool, Lycra and shrink polyester – have been applied to the technique. An additional yarn - 30/1 Japanese high twist wool – was also used due to its effectiveness in initial yarn tests for manipulating a simple plain weave into undulating ridges.

52/2 High Twist Wool: a soft fluid and deep pleated effect was generated. When extended the fabric has a soft springy stretch. The appearance of the cloth is untidy due to loops forming on the surface of the cloth.

30/1nm Japanese High Twist Wool: a soft, fluid and deep pleat was generated, again with a soft springy stretch. The surface of the fabric is neat and compact with no looping.

Lycra (& mercerised cotton): no form was generated, instead a flat slightly stretchy cloth was created, with significant width shrinkages.

60/2 shrink polyester (& mercerised cotton): no form was generated, instead a flat balanced cloth with a rib pattern was created. Significant and consistent width shrinkage was also achieved.</td><td>The intended effect was achieved in two out of the four samples. However, the limited surface disruption and looping in the Japanese wool samples makes the yarn preferable to the 52/2 wool. The fabric has a neater and cleaner appearance with the weft yarns bedding in to the warp yarn rather than sitting and looping on the surface of the cloth – the cloth is more stable and would be less prone to snagging.

The pleating effect is much more fluid and natural than the corded pleat effect, the fabric is springy and stretchy and so presents an alternative method of controlling fullness. It could also be applied to shaping, fitting and facilitating movement if applied selectively within garments.

The Lycra and shrink polyester resulted in flat rather than pleated fabrics – not the intended effect. However, significant levels of width reduction were achieved, with the fabric density increased by the movement of the weft yarns. As such there is potential for applying these yarn/structure combinations for shaping and fitting in panels where width reduction is required but increased bulk or form is not. They present opportunities for a closer fit.

The most significant finding here is that the shrink polyester's activity is not impeded or affected by the weave structure – the shrinkage remains consistent and continuous through the length of the yarn. The Lycra and the wool on the other hand are influenced by weave structure, demonstrating that the wool, Lycra and polyester work in different ways and have different responses and effects.

Shrink polyester: length of yarn shrinks evenly – 'activity' cannot be controlled or focused in a specific area through weave structure – the shrink is solid and permanent.
High twist wool: the yarn's activity is influenced and inhibited by structure - it requires space to move and curl in order to manipulate the cloth – width reduction is achieved through curling and twisting and so can be extended.</td><td>The warp/weft facing folding technique is effective and (as described) could have multiple functional applications within the construction of a garment. As such the impact of surrounding fabrics on the technique needs to be tested. To be established:
• Does the scale of the panels of warp and weft facing structures impact on the level of manipulation?
• Is the manipulation/activity inhibited if placed next to panels of entirely passive cloth?
• Can the surrounding cloth be intentionally constructed to inhibit folding to focus the manipulation elsewhere?

Current samples have combined multiple yarn types, achieving the same effect in a 100% wool fabric would be preferable for sustainability and care reasons.

Although unintended the flat fabrics offer their own opportunities and benefits for shaping and fitting without the creation of bulk. The Lycra offers a level of comfort stretch, whilst the polyester offers permanent reduction and stability. Again, the impact of surrounding fabrics on yarn and structure capabilities needs to be tested (as above).

The lack of control over the activity of the polyester and its even and consistent shrink means that its ability to taper rather than evenly shrink a fabric or garment may be limited (even non-existent). As the polyester (so far) is the only yarn sourced that provides permanent and stable shrink (non-stretch) this raises questions about the types of garments (or components) that could be achieved, unless methods can be developed to selectively place and isolate the yarn in particular sections or panels of a cloth to control and influence shrinking and shaping.</td><td>The results achieved with the wool mean that there is potential to shape and fit (through pleating) without the need for pressing and intensive manipulation in the finishing stage. It also means that there is potential for creating garment/components that use a single fibre type – this is beneficial for the sustainability of the process and the garments/fabrics, and as wool is widely available in a range of types there is scope for producing a range of fabric types.

Combining warp and weft facing structures depending on threading and shaft allocation – with a minimum of 8 shafts required. This will limit garment styling and shaping options on the hand-loom. However, alternative techniques that are not shaft dependent are being developed and could be combined with the pleating technique to increase styling options.

The most effective high twist wool – Japanese high twist – has been tested on the Jacquard and is not compatible with the machine. This means that the techniques developed using this yarn will not be directly transferable to the Jacquard loom. The 52/2 wool is compatible with the loom, and so there is scope for effectively translating techniques using an alternative yarn(s).

In order to control shaping when using shrink polyester, complex panelling and panel shaping is likely to be required. This could be explored in conjunction with the development of the catch-in technique (see Panelling Review Sheet) on the hand loom but would be more complicated on the Jacquard loom as partial insertions of yarn are not possible.</td><td>1. Hand weaving development to take place using Lycra, 30/1nm Japanese high twist wool and shrink polyester – eliminate 52/2 wool from testing with this technique.

2. Test warp and weft facing technique with increased panel scales to assess impact on the level and control of the manipulation and shrink.

3. Test existing structures and yarn combinations alongside sections of plain fabric with no active yarn to access the impact on the manipulation and shrink effect.

4. Undertake tests to explore panelling of wool pleating, using the catching-in technique (to isolate and inhibit yarn activity).

5. Undertake tests to assess panelling of polyester shrinkage, using catching–in technique to influence the level of shrink across the width of the cloth.

6. Source and experiment with 100% wool fabrics using high twist wool for pleating effects.</td></tr>
</table>

	Moves >	Consequences >	Implications >	Appreciations >	Further Moves >
		Lycra: shrinkage occurs along the length of the yarn – the activity is affected by the weave structure – longer floats facilitate greater stretch and movement – activity can be controlled and focused to some extent. This can now be used to make more informed decisions about the suitability of yarns for different techniques.			
Stage #4	A single very small sample using the corded pleat structure (knife pleat) tested on the Jacquard using 1/30 Felting Lambswool. A self-fold effect was not achieved, ridges were created with some forwards and backwards movement in the panels achieved. Despite being a felting wool, the lambswool did not felt even in a 90° machine wash.	It is widely acknowledged that a minimum of 12" needs to be woven for collapse weave processes to be successful, and so this particular yarn and structure combination should be tested in a larger sample. However, testing of 3D folding fabrics (which are based on the principles of corded pleats) have been selected to take priority for development of the Jacquard, as it will be possible to apply successful yarn combinations to the corded pleat technique. Decision: no further development on the Jacquard at this stage. Although the pleating effect was not achieved the felting wool provided a stiffer base cloth than other yarn combinations applied to Jacquard sampling. I suspect the limpness of existing base cloths tested with complex 3D folding is inhibiting movement and generation of structure. As such the felting wool (and other wools) will now be tested as a base cloth for 3D folding. The sample produced used a plain weave combined with a 48 EPI warp, this may have restricted the movement and exposure of the wool's fibres, inhibiting felting. As it is not possible to alter the density of the warp on the Jacquard, longer float structure could provide an alternative solution. See 3D folding fabrics review for further discussion of the pros and cons.	Pausing the development of corded pleats on the Jacquard at this stage will have no significant impact on the testing of yarns, development of the process or garment components, due to the transferability of the principles from 3D folding fabrics. However, to ensure that an effective technique for controlling fullness and pleating is developed using the Jacquard, I will now explore and experiment with warp and weft facing structures as a means of pleating cloth. This has been a particularly successful aspect of hand woven sampling, and so there is scope for successful application to the Jacquard using compatible wool.	There are no significant negative impacts on the development of garments, on sustainability or the transition from hand to digital production. The move from hand to digital for warp and weft faced pleating presents new opportunities to develop this technique into shaped and panelled pleats in a way that would not be possible on the handloom.	1. Put on hold the development of corded pleats on the Jacquard, instead focusing on the development of 3D folding fabrics. 2. Use the Jacquard to test warp and weft facing pleating (following on from the success with hand weaving). 3. See Design Review Protocol for 3D Folding Fabrics for further developments using felting wool as a base cloth.
Stage #5	Warp & weft facing pleating using the Jacquard: the technique has been tested using a combination of 1/7 and 7/1 twills, in 1" and 0.5" widths using 52/2 high twist wool as the 'active' (based on compatibility with the Jacquard and previous outcomes. Although a small amount of movement has been achieved, the result is minor rippling (a crease-like effect) rather than effective pleating. Despite the float lengths being extended (in comparison to hand woven examples) to accommodate the 96 EPI, the warp density has proven to be too great and has diminished any creation of form.	This selection of samples was produced using single cloth, and as such, using the Jacquard warp at its highest density. There is therefore scope for working with double cloth to reduce the EPI to 48, allowing more space for the 'active' yarn to move. However, in the past double cloth samples have proven to be too open and unstable. A positive outcome of the production of these samples relates to aesthetics rather than function, with the strong contrast of black and ecru yarns in warp and weft facing structures creating bold and graphic effects that have potential for further development both in hand and jacquard weaving. In hand weaving where warp and weft facing pleating has been successful, this type of patterning would have both a functional and	The reduction of the EPI on the Jacquard loom is limited to using double cloth, raising issues of structural instability (experienced in other samples – see 3D folding fabrics). Using a slightly thicker high twist wool (subject to loom compatibility) could be explored to resolve this issue. The arrival of the new TC2 loom would resolve all of these issues, as the EPI of the warp (and yarn type) can be selected accordingly, and the manual feed/shuttling of the weft means that restrictions on weft yarn will be alleviated. Therefore, yarn flexibility and single end control can be combined to facilitate effective production of warp and weft based pleating (based on hand woven findings) that can be applied selectively to sections of the cloth – the pleats themselves could even be shaped and contoured.	If continuing to work on the current Jacquard loom, warp and weft faced pleating would probably need to be eliminated from the research (due to time constraints for the testing of alternative yarns). This would then limit scope for combining a range of shaping techniques within an individual garment component. Pursuing warp and weft faced pleating on the handloom alone for use in garment components, would limit their use to straight pleats across the full width or sections of the cloth. However, it is more probable that a 100% wool component (for recycling/sustainability purposes) could be developed due to warp selection flexibility.	1. Place the development of warp and weft pleating structures using the Jacquard on hold, until arrangements for the TC2 have been made. 2. Explore shaped pleats and panelling in toile form to assess cope and potential suitability for garment fitting and shaping. 3. Continue to apply the use of warp and weft facing pleats on the hand loom – apply to garment component prototype combined with catching-in (prototype Review Protocol needed). 4. Source wool suitable for use in the warp to produce 100% wool pleats.

Component Construction: Design Review & Development – Rigid/Flexible Fabrics

	Moves >	Consequences >	Implications >	Appreciations >	Further Moves >
Stage #1	A number of wool yarns have been tested and combined with a polyester warp on the hand loom, using plain weave. A single wool yarn has been tested using a diamond pattern. All the samples were finished in the washing machine on a 60° cycle. The intention was for the wool yarns to felt to create a fabric with stiffness that could subsequently be combined with lighter more flexible fabrics. Felting has not occurred in any of the samples. Note: prior to the completion of samples, alternative methods of creating contrasting flexibility/rigidity have been considered/thought of. These are: 1. Using wire/silk yarns and bundled yarns to create rigid sections of cloth – either in stripes or alternative shapes (below). 2. Using a catching-in technique to create shaped panelling using the types of yarns referred to above. 3. Creation of boning effects by inserting and trapping rigid materials between two layers of cloth – possibly combining these with 'active' yarns to manipulate, fold and flare. 4. Finding yarns that react to heat, melting and solidifying or becoming bendy to apply to the methods above.	The wool weft was combined with a polyester (non-felting) warp, had a wool warp been used greater potential for felting (with warp and weft felting together) could have been generated. The wool yarns selected were reasonably fine and smooth, rather than being particularly fibrous and fluffy. This may have inhibited felting action. In addition, the yarns used were sourced from the yarn store, as such full details of the yarns are not available, making it difficult to judge if they are suited to felting. Samples were finished in the washing machine rather than by hand, so the level of agitation and the temperature was set rather than adjustable. Finishing the samples by hand would have allowed greater flexibility and observation of the wool's reaction to the temperature and movement.  Diamond Pattern Sample Using Wool in Weft (front & back)	Using 100% wool for the fabric construction would result in full felting rather than selected felting of panels or shapes, as such it would be difficult to achieve two contrasting weights/handles in the cloth. It would be possible in stripes (either in the warp or the weft) but achieving it in shapes would be problematic/impossible. Also this would not be transferrable to the Jacquard loom as its warp is cotton. Sourcing and testing wool yarns of different types, thicknesses etc. both from the yarn store and elsewhere would be quick and simple and could be done alongside the development of other fabrics both on the hand and the Jacquard loom. The only negative implication is the cost of sourcing new yarns and the associated waste of yarns that are found to be unsuitable (this does not mean that they would be unusable elsewhere in the research). For sampling, due to their small scale, finishing fabrics by hand is not problematic, however, when applied to larger fabrics and garments achieving uniform and consistent results by hand could be problematic. Initial finishing by hand could be used to understand the reaction and process, before moving to machine finishing later. An additional consideration is: do I want fabrics and garments to be machine washable or hand-wash only? This to some extent is determined by the intended use and function. The new ideas (yet to be tested), in particular the catching-in technique (and possibly the boning effect) could only be achieved on the hand loom. Other yarns, such as silk/wire would need to be tested on the Jacquard loom to establish compatibility.	For sustainability reasons (recycling possibilities) single fibre fabrics are the ideal. Moving the development of this fabric type to the Jacquard loom, means that in sampling at least, this will not be possible. However, the intention is to create fabrics based on triangular tessellation (based on wireframe modeling) and so more flexibility for creating more complex patterns (rather than just stripes) demands the use of multiple yarn types. As such a criteria for yarn use and mixing needs to be established – making decisions about this at this stage may limit fabric development opportunities. In order to create complex tessellating designs, the flexibility of single end control will be required. Therefore the Jacquard loom will be required. This will place some restrictions on the thickness of the yarn that can be used. This actually provides useful criteria for selection and testing of yarns – providing boundaries. The catching-in technique and potentially some of the other new and untested ideas, may be limited to hand production, which places limitations of garment shaping. However, I have already made the decision that garments and fabrics will be pursued using both formats – some will be transferable/translatable and others will not.	1. Based on ease of access, wool yarns will be tested on the hand loom, but in selecting the yarns I will use the thickness restrictions of the Jacquard as a criteria. 2. Yarn testing and selection to take place before CAD development of tessellating patterns – testing and confirming the basic principles of the design idea before advancing further. 3. Initially finishing to be undertaken by hand to develop an understanding of the process (allowing for close observation and analysis), before transferring to the machine. 4. New ideas (detailed) to be explored on the hand loom, to test the basic principles, before deciding which to take forward. 5. Decisions regarding yarn usage criteria (for sustainability reasons) to be postponed, so that possibilities and development opportunities are not limited too soon. **Note:** this design idea has, through reflection, split into two strands – complex tessellation using wool felting, and panelling using catching-in and boning techniques. The principle of contrasting fabric weights and handles is the basis for both strands, but the methods demand different construction formats.

Appendix 2:

Pointcarre Digital Pattern and Jacquard Production Process

A2.1. Pointcarre Software Overview

Pointcarre is a widely available weave software used for the 'drawing', digitisation and preparation of woven textile designs for Jacquard production[1]. The software includes design tools, structure and yarn libraries, as well as fabric simulation capabilities. Pointcarre is compatible with multiple image file formats, including: JPEG, TIFF, and PNG, facilitating importation of digital patterns and designs generated in CAD packages such as Adobe Illustrator and Photoshop. The software interfaces with "all Jacquard heads" (Pointcarre 2018), and so is suitable for use with both the TC2 and Jacquard power loom.

A2.2. Pointcarre Digitisation Process for CPW

Figure A2.1 shows the Pointcarre digitisation process developed throughout this research for the production of composite woven patterns. Two different methods of pattern design and digitisation were developed, with more complex garment lay-plans produced in Adobe Illustrator (i.e. the composite top) and then imported into Pointcarre, and simpler designs and constructions 'drawn' directly into Pointcarre.

[1] Pointcarre can also be used for Dobby design, preparation and production, but was not applied for this purpose in this study.

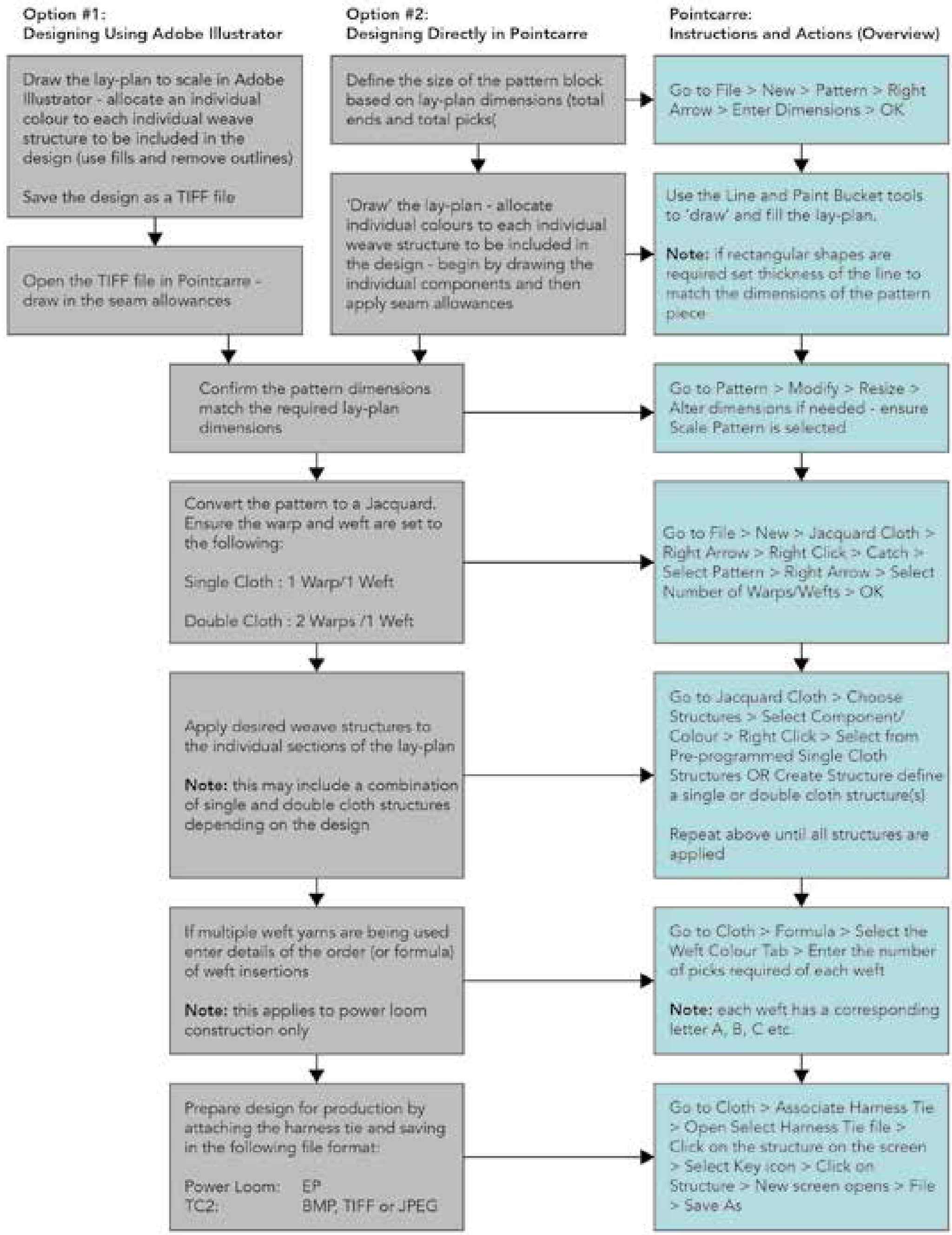


Figure A2.1: Pointcarre Digitisation Process for Composite Pattern Weaving (2018)
Illustration by Anna Piper

Appendix 3:

Zero Waste Pattern Cutting Design and Drafting

A3.1. Zero Waste Pattern Types

Four methods are usually associated with ZWPC – Tessellation, Jigsaw, Embedded Jigsaw and Multiple Cloth (Rissanen & McQuillan 2016; Carrico & Kim 2014; McQuillan 2011). Whilst these are often referred to as "approaches" they relate specifically the type of pattern/lay-plan produced. Table A3.1, describes the individual methods and the underlying principles associated with them[2].

This research uses the Jigsaw as a basis for garment design, with a single garment being created from a single piece of cloth. The use of multiple pieces of fabric is negated by CPW, as pattern and fabric quality can be altered and engineered to suit a garment whilst still being produced from one fabric length. Whilst Jigsaw is applied consistently across all garments, the approaches used to design and draft the pattern vary (see Chapter 7).

A3.2 Drafting and Design Approaches

In describing a workshop led by Holly McQuillan at Aalto University in 2012, Niinamki Ed. (2013) identifies three approaches to drafting patterns and designing zero waste garments[3]. These are:

[2] Table A3.1 is based on information from the following sources: Rissanen & McQuillan 2016; Carrico & Kim 2014 and McQuillan 2011.

[3] These approaches are also briefly referred to in Rissanen & McQuillan's 2016 publication 'Zero Waste Fashion Design. Neither Rissianen & McQuillan or Niinamki Ed. (2013) expand upon these approaches in any significant detail.

Method	Description	Principles
Tessellation	• A tessellating repeat pattern consisting of a single shape, such as a triangle, that is repeated multiple times	• The interlocking shapes fill the rectangular piece of fabric • The repeat unit (or shape) may varying in scale • The pattern pieces may be layered to form the garment design • The garment design may be generated and evolve on the mannequin rather than being predetermined • The pattern pieces can be used to generate multiple garment designs
Jigsaw	• A series of interlocking pattern pieces that fill the fabric to produce a single garment	• The pattern consists of multiple and varied shapes • Each pattern piece shares its cut edges with adjacent pieces • The pattern can incorporate both curved and straight cut-lines and pieces • The pattern may be built around a single fixed shape or conventional pattern block • The primary aim is to eliminate cutting waste rather than minimise fabric usage
Embedded Jigsaw	• Integration of a traditionally designed garment pattern with a zero waste pattern	• See Jigsaw method above • The traditional pattern forms a fixed area, with another garment designed to utilise the waste
Multiple Cloth	• One or more garments produced from multiple pieces of cloth	• See Jigsaw method above • A single garment may be produced using two fabrics with different colours and/or textures • Multiple garments may be produced using multiple fabrics with different qualities

Table A3.1: Zero Waste Pattern Cutting Approaches and Principles

Planned Chaos:	using and adapting conventional pattern blocks as a starting point for pattern and garment design
Geo Cut:	design with abstract shapes (e.g. rectangles, triangles and circles) and the use of geometry to create the design
Cut and Drape:	working with a length of fabric on the mannequin, and pinning, cutting and draping

Whilst these approaches are individually categorised, it is recognised that using them in combination is "likely to provide the richest results." (Rissanen & McQuillan 2016: 89).

Appendix 4:

Recyclability: Natural Versus Synthetic

Fibre Type	Advantages	Disadvantages
Natural Fibres	• Renewable source material • Biodegradable	• High demand for agricultural land • High water consumption in production (cotton)[4] • Fibre quality degraded when recycled
Synethic Fibres	• Low water consumption in production • Fibre quality can be maintained when recycled • Lower energy requirements for care	• Non-renewable source material • High energy consumption during production • Micro-fibre shedding when washed • Non-biodegradable

Table A4.1: Principal Environmental Advantages and Disadvantages of Natural and Synthetic Fibres

Table A4.1 demonstrates that both natural and synthetic fibres are recyclable. Whilst natural fibres may consume fewer natural resources during recycling, they are degraded by the processing and ultimately (over time) become unusable. Synthetic

[4] The water consumption in the production of textile fibres varies greatly, and there is no correlation between the category of fibre (natural or synthetic) and the level of water consumption. For example, cotton production involves very high levels of water consumption, whilst the water consumption for wool production is relatively low.

fibres are infinitely recyclable (with no reduction in quality), they are not however biodegradable and facilities for the recycling of synthetics are currently more limited than those for recycling natural fibres (Greenpeace 2016: 6).

As the debates surrounding fibre sustainability continue, there remains no definitive answer – no single fibre is considered to be the most sustainable. Moreover, no category of fibre – natural or synthetic is collectively deemed to be the most environmentally sound. Recyclability should not, therefore, be the only criterion upon which fibre, yarn and material selection is based. Factors relating to suitability for application and durability (functional and emotional) (Section 6.3) must also be considered. Designers must make up their own minds, and make informed decisions based on their own practice, principles and products.

Appendix 5:

Technical Sampling Records

Hand Weaving Warp #1: Yarn Shrink, Fold & Flexibility Testing

Warp Set-up	Yarn	27 Tex Polyester (White)	EPI	40	Sett	36	Reed	14s	Ends Per Dent	2/3 alternate	Draft	Pointed	Shafts	14	Total Ends	546

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage (%)	Effect(s)	Yarn Comments	General Comments
W1P1S1	2/44 Wool (charcoal)	Plain	W15" x H2.625"	60 Degree - Fastwash	W15" xH2.75"	Negligible	• Tracking	• Yarn perhaps not thick enough or fibrous enough	• No felting achieved. Some unraveling occurred in washing
W1P1S2	Wool (fluro yellow)	Plain	W15" x H2.375"	60 Degree - Fastwash	W14" x H2.375"	7%	• Very mild tracking and limited shrink	• Yarn perhaps not thick enough or fibrous enough	• No felting achieved
W1P1S3	2/30nm Merino Wool (charcoal)	Plain	W15" x H2.5"	60 Degree - Fastwash	W15" x H2.5"	Negligible	• Tracking	• Yarn perhaps not thick enough or fibrous enough	• No felting achieved. Some unravelling occurred in washing
W1P1S4	1/27 Wool Crepe – Z (ecru)	Plain	W15" x H2.625"	30 Degree Fastwash - 800 Spin	W6" x H2.75 "	60%	• A clean and defined fine fold/pleat - semi regular with even front/back undulation depth	• Very fine yarn with slight roughness	
W1P1S5	52/2nm (14TPI) Wool (ecru)	Plain	W15" x H2.625"	30 Degree Fastwash - 800 Spin	W15" x H2.75"	None	• Mild tracking with slight movement in warp and weft	• Creates a light and open cloth	• No activity – could be used as passive yarn
W1P1S6	40/1nm High Twist Cotton (white)	Plain	W15" x H2.875"	30 Degree Fastwash - 800 Spin	W15" x H2.875"	None	• Very mild ripples or creases	• Creates a light, open and even cloth with balance	• Significant curl when sample separated (pre & post finish)
W1P1S7	60/2nm Shrink Polyester (white) & 60/2 Silk (blue) - alternate	Plain	W15" x H2.875"	Steambed	W11.625" x H2.875"	22.5%	• Even reduction of cloth with slight relief and texture generated	• Creates a light and even cloth with increased density	
W1P1S8	60/2nm Shrink Polyester (white)	Plain	W15" x H3"	Steambed	W11.625" x H2.875"	22.5%	• Even reduction of cloth width creating a smooth and compact surface	• Light fine cloth with no bulk, and consistent but increased density	
W1P1S9	2/30nm Merino Wool (charcoal), 27 Tex Polyester (grey) & Wool (fluro yellow)	Plain	W15" x H5.5"	60 Degree - Fastwash	W15" x H5.5"	None	• Obvious tracking in wool and mild tracking in polyester sections	• Yarn perhaps not thick enough or fibrous enough	• 1" alternate stripes with yellow fluro outline- no movement or felting achieved
W1P1S10	60/2nm Shrink Polyester (white) & 27 Tex Polyester (white & grey)	Plain	W15" x H5.675"	Steambed	W11.625" x H2.875" in shrink sections	22.5%	• Soft horizontal seersucker - light, open, stable and smooth cloth with elegant gathers/ripples	• The combination of yarns has resulted in a fairly consistent appearance rather than a contrast	• 1" alternate stripes with grey outline
W1P2S1	2/44 Wool (charcoal) & 27 Tex Polyester (white)	Plain - Diamond Extra Weft	W15" x H6.125"	60 Degree - Fastwash	W14.5" x H6.125"	3%	• Minor relief diamond pattern	• Yarn perhaps not thick enough or fibrous enough	• No felting achieved
W1P1S11	28/2nm Cashwool (white)	Plain	W15" x H3"	Steambed	W13" x H3"	13%	• Some tracking and shrink – no form	• Soft inherent stretch suitable for comfort fit rather than significant shaping	
W1P1S12	28/2nm Cashwool (black)	Plain	W15" x H3.125"	Steambed	W13" x H3"	13%	• Some tracking and shrink – no form	• Soft inherent stretch suitable for comfort fit rather than significant shaping	
W1P1S13	Viscose Elite Body (white)	Plain	W15" x H3.25"	Steambed	W10.875" x H3.25"	27.5%	• Consistent fabric surface with shrink and soft stretch	• Could be used for shaping and comfort stretch – consistent and lustrous appearance	
W1P1S14	Puma Stretch Viscose (black)	Plain	W15" x H3.25"	Steambed	W12" x H3.25"	20%	• Consistent fabric surface with shrink and soft stretch	• Soft inherent stretch suitable for comfort fit rather than significant shaping	

Hand Weaving Warp #1: Yarn Shrink, Fold & Flexibility Testing (AVL Dobby)

Warp Set-up	Yarn	27 Tex Polyester (White)	EPI	40	Sett	36	Reed	14s	Ends Per Dent	2/3 alternate	Draft	Pointed	Shafts	14	Total Ends	546

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage (%)	Effect(s)	Yarn Comments	General Comments
W1P1S15	30/1nm Japanese High Twist Wool – S (black)	Plain	W15" x H3.5"	30 Degree Fastwash - 800 Spin	W6.5" x H3.5"	57%	• A reasonably even and uniform pleating is achieved – mild irregular undulations in places – light and unbulky	• Gives a light and springy cloth whilst retaining a smooth surface	• Significant curl when sample separated (pre and post finish)
W1P1S16	30/1nm Japanese High Twist Wool – Z (black)	Plain	W15" x 3.5"	30 Degree Fastwash - 800 Spin	W6.5" x H3.5"	57%	• A reasonably even and uniform pleating is achieved – mild irregular undulations in places – light and unbulky	• Gives a light and springy cloth whilst retaining a smooth surface	• Significant curl when sample separated (pre and post finish)
W1P1S17	14.5nm High Twist Merino – S (ecru)	Plain	W15" x H4.875"	30 Degree Fastwash - 800 Spin	W8.5" x H4.875"	43%	• Fine, uneven and multi-directional vertical pleating and folding	• Slightly rough to the touch and fluffy looking cloth – springy stretch but with limited extension	• Significant curl when sample separated (pre and post finish)
W1P1S18	Lycra (black) & 27 Tex Polyester (white)	Plain	W14" x H3"	Steambed	W9" x H3"	36%	• Accentuated tracking and textural effect	• Soft and weak stretch – yarn not suited to use on own	
W1P1S19	5x85 Den Silk & 12% Elastomer (ecru)	Plain	W15" x H3.375"	Steambed	W6.25" x H3.375"	58%	• Significant shrink with textured effect	• Results in very rough handle but powerful stretch	
W1P1S20	52/2 High Twist Wool – S (ecru)	Plain	W15" x H3.5"	30 Degree Fastwash - 800 Spin	W6" x H3.5"	60%	• Even and fine natural vertical pleating with soft and springy extension and texture.	• Relatively smooth and compact fabric and structure, with effective pleating	
W1P1S21	4x44 Den High Twist Silk – Z (grey)	Plain	W15" x H3.25"	30 Degree Fastwash - 800 Spin				• Yarn difficult to wind on and work with – twists back on itself very easily	
W1P1S22	4x44 Den High Twist Silk – S (ecru)	Plain	W15" x H2.875"	30 Degree Fastwash - 800 Spin				• Yarn difficult to wind on and work with – twists back on itself very easily	
W1P1S22	30/1nm Japanese High Twist Wool – S (black) & 30/1nm Japanese High Twist Wool – Z (black)	10+4, 20+4, 30+4 etc. Plain Alternating Increasing Stripes	W15" x H12"	30 Degree Fastwash - 800 Spin	W5.5" x H12"	63%	• An even, multi-directional folding, with distinct horizontal lines where the yarn twist is altered.	• Suited to shaping and creating close fit and stretch when used in combination with this structure and construction	
W1P1S23	30/1nm Japanese High Twist Wool – S (black) & 30/1nm Japanese High Twist Wool – Z (black)	2x2,4x4,6x6 etc. Plain Alternating Increasing Stripes	W15" x H11.375"	30 Degree Fastwash - 800 Spin	Tapering with a Max - W13.5 & Min W10.75	10% at widest point & 28% at narrowest	• Patchy texture, gradually diminishing into a flat fabric with subtle tracking	• The effect generated is not sufficient to shape or taper the cloth when used in combination with this structure and construction	
W1P1S24	27 Tex Polyester (grey) & 30/1nm Japanese High Twist Wool – S (black)	Plain – Alternate 0.5" Stripes	W15" x H2.875"	30 Degree Fastwash - 800 Spin	W14.25" x H2.875"	5%	• Small amount of undulation and tracking has occurred in the high twist stripes – not enough to manipulate the polyester	• The effect created by this yarn combination is not suited to any functional or shaping purpose	
W1P1S25	27 Tex Polyester (grey) & Viscose Elite Body (white)	Plain – Alternate 0.5" Stripes	W15" x H3"	No applicable			• Error in construction – see technical write-up	• Error in construction – see technical write-up	• Error in construction – see technical write-up
W1P1S26	27 Tex Polyester (grey) & 14.5nm High Twist Merino – S (ecru)	Plain – Alternate 1"/0.5" Stripes	W15" x H3.5"	Steambed	W8.5" x H3.5"	43%	• Effective gathering and pleating effect has been generated.	• Contrasting surfaces and levels of gathering generated	• There is potential for use in functional shaping but some restrictions may be placed on this due to the bulkiness of the cloth
W1P1S27	27 Tex Polyester (grey) & 52/2 High Twist Wool – S (ecru)	Plain – Alternate 0.5" Stripes	W15" x H3"	Steambed	W8" x H3"	47%	• Effective gathering and pleating effect has been generated	• Contrasting surfaces and levels of gathering generated – the activity of the active yarn has been limited slightly by the inactive yarn	• Does not have the strength to compress or hold – doesn't have the bulkiness of the previous sample
W1P1S28	27 Tex Polyester (grey) & Lycra (black) with 27 Tex Polyester (white)	Plain – Alternate 0.5" Stripes	W14" x H2.5"	Steambed	W10" x H2.5"	44%	• A light gathering and seersucker effect created	• The combination of yarns gives a light cloth and some light structure and support	• Could be applied for comfort and mild expansion for movement
W1P3S1	27 Tex Polyester (black) & 60/2nm Shrink Polyester	Plain – Diamond Extra Weft (fold)	W15" x H11.25"	Steambed	W11.25" x H11.25"	25%	• Slight relief pattern rather than 3D form created	• Polyester base cloth not stiff enough to result in any creation of form	• Continuing development and testing of yarn combinations required with this lifting plan

Hand Weaving Warp #1: Yarn Shrink, Fold & Flexibility Testing (AVL Dobby)

Warp Set-up	Yarn	27 Tex Polyester (White)	EPI	40	Sett	36	Reed	14s	Ends Per Dent	2/3 alternate	Draft	Pointed	Shafts	14	Total Ends 546

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage (%)	Effect(s)	Yarn Comments	General Comments
W1P3S2	27 Tex Polyester (grey) & 30/1nm Japanese High Twist Wool – S (black)	Plain – Diamond Extra Weft (fold)	W15" x H11.5"	60 Degree - Fastwash	W13.75" x H11.5"	8%	Slight relief pattern rather than 3D form created	• Polyester base cloth not stiff enough to result in any creation of form – activity of wool inhibited by weave structure	• Continuing development and testing of yarn combinations required with this lifting plan

Hand Weaving Warp #2: Yarn Shrink & Pleating (Blanket Warp)

Warp Set-up	Yarn	27 Tex Polyester (Black)	EPI	40	Sett	44	Reed	22	Ends Per Dent	2	Draft	Blanket Block	Shafts	16	Total Ends	544
Warp Set-up	Yarn	50s Linen (Ecru)	EPI	32	Sett	32	Reed	22	Ends Per Dent	1 / 2 Alternate	Draft	Blanket Block	Shafts	16	Total Ends	448

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage /Width Reduction (%)	Effect(s)	Yarn Comments	General Comments
W2P1S1A	27 Tex Polyester (Black) & 60/2nm Shrink Polyester (White) – Linen Warp	Cord Pleat (Plain)	W12" x H6.5"	Steam Bed	W10" x H6.5"	17%	• Strong neat pleating with a sharp edge – good spring back.	• Not strong enough to self pleat – pressing needed. • Polyester balances the linen's stiffness. • Light unbulky cloth.	• Base cloth disruption removed with pressing.
W2P1S1B	27 Tex Polyester (Black) & 60/2nm Shrink Polyester (White) – Polyester Warp	Cord Pleat (Plain)	W11.75" x H6.5"	Steam Bed	W9" x H6.5"	23%	• Strong neat pleating with a sharp edge – good spring back.	• Not strong enough to self pleat – pressing needed. • Soft, light, and unbulky cloth.	• Base cloth disruption removed with pressing.
W2P1S2A	50s Linen (Ecru) & 60/2nm Shrink Polyester (White) – Linen Warp	Cord Pleat (Plain)	W12.25" x H6.75"	Steam Bed	W9.375" x H6.75"	23%	• Strong but untidy pleats achieved.	• Not strong enough to self pleat – pressing needed. • Significant disruption of the linen weft throughout the cloth. • Very rough handle	• Base cloth disruption not removed with pressing. • Not a useable cloth due to handle.
W2P1S2B	50s Linen (Ecru) & 60/2nm Shrink Polyester (White) – Polyester Warp	Cord Pleat (Plain)	W11.875" x H6.75"	Steam Bed	W8.75" x H6.75"	26%	• Strong but untidy pleats achieved.	• Not strong enough to self pleat – pressing needed. • Significant disruption of the linen weft throughout the cloth. • Polyester softens the cloth • Untidy linen loops – resulting in roughness.	• Base cloth disruption not removed with pressing. • Not a useable cloth due to handle.
W2P1S3A	2/16ne Mercerised Cotton (Grey) & 60/2nm Shrink Polyester (White) – Linen Warp	Cord Pleat (Plain)	W12.5" x H6.125"	Steam Bed	W10" x H6.125"	20%	• Strong defined pleat – good spring back	• Not strong enough to self pleat – pressing needed. • Cotton does not balance linen's stiffness. •	• Base cloth disruption removed with pressing.
W2P1S3B	2/16ne Mercerised Cotton (Grey) & 60/2nm Shrink Polyester (White) – Polyester Warp	Cord Pleat (Plain)	W11.875" x H6.875"	Steam Bed	W9" x H6.125"	24%	• Strong and defined pleat – good spring back.	• Not strong enough to self pleat – pressing needed. • A significant amount of looping of the cotton occurs.	• Base cloth disruption not removed with pressing.
W2P1S4A	27 Tex Polyester (Black) & 30/1nm Japanese High Twist Wool – S (Black) - Linen Warp	Cord Pleat (Plain)	Finished without measuring in error.	Machine Wash - Wool Cycle - 40 - 800 spin	W11.2" x H5.75"	Unknown	• Small amount of float movement – no structure generated.	• No active effect with this yarn & structure combination.	• Not a usable combination.
W2P1S4B	27 Tex Polyester (Black) & 30/1nm Japanese High Twist Wool – S (Black) – Polyester Warp	Cord Pleat (Plain)	Finished without measuring in error.	Machine Wash - Wool Cycle - 40 - 800 spin	W10.2" x H6"	Unknown	• No active effect.	• No active effect with this yarn & structure combination.	• Not a usable combination.
W2P1S5A	2/16ne Mercerised Cotton (Grey) & 30/1nm Japanese High Twist Wool – S (Black) – Linen Warp	Cord Pleat (Plain)	Finished without measuring in error.	Machine Wash - Wool Cycle - 40 - 800 spin	W11.5" x H5.5"	Unknown	• Small amount of float movement – no structure generated.	• No active effect with this yarn & structure combination.	• Not a usable combination.
W2P1S5B	2/16ne Mercerised Cotton (Grey) & 30/1nm Japanese High Twist Wool – S (Black) – Polyester Warp	Cord Pleat (Plain)	Finished without measuring in error.	Machine Wash - Wool Cycle - 40 - 800 spin	W11" x H6"	Unknown	• No active effect.	• No active effect with this yarn & structure combination.	• Not a usable combination for structure generation.
W2P1S6	50s Linen (Ecru) & 30/1nm Japanese High Twist Wool – S (Black)	Cord Pleat (Plain)	Finished without measuring in error.	Machine Wash - Wool Cycle - 40 - 800 spin	W10.3" x H6.3"	Unknown	• No active effect.	• No active effect with this yarn & structure combination.	• Not a usable combination for structure generation.

Hand Weaving Warp #2: Yarn Shrink & Pleating (Blanket Warp)

Warp Set-up	Yarn	27 Tex Polyester (Black)	EPI	40	Sett	44	Reed	22	Ends Per Dent	2	Draft	Blanket Block	Shafts	16	Total Ends	544
Warp Set-up	Yarn	50s Linen (Ecru)	EPI	32	Sett	32	Reed	22	Ends Per Dent	1 / 2 Alternate	Draft	Blanket Block	Shafts	16	Total Ends	448

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage /Width Reduction (%)	Effect(s)	Yarn Comments	General Comments
W2P1S7	27 Tex Polyester (Black) & 14.5nm High Twist Merino – S (Ecru)	Cord Pleat (Plain)	Finished without measuring in error.	Machine Wash - Wool Cycle - 40 - 800 spin	W4" x H5.75"	Unknown	• Good pleat with soft edges & 3D structure – good spring back.	• Not strong enough to self pleat – pressing needed. • No surface disruption. • Fluffy surface – on the verge of felting.	
W2P1S8	50s Linen (Ecru) & 14.5nm High Twist Merino – S (Ecru)	Cord Pleat (Plain)	Finished without measuring in error.	Machine Wash - Wool Cycle - 40 - 800 spin	W8.75" x H6"	Unknown	• Full fabric rather than float focused shrinking.	• Full fabric started to felt. • Yarn has potential for tapered shaping rather than form.	Not a usable combination for structure generation – possible tapering application.
W2P1S9	2/16ne Mercerised Cotton (Grey) & 14.5nm High Twist Merino – S (Ecru)	Cord Pleat (Plain)	Finished without measuring in error.	Machine Wash - Wool Cycle - 40 - 800 spin	W9.75" x H6.5"	Unknown	• Full fabric shrink – small amount of float manipulation	• Full fabric started to felt. • Small amount of surface disruption.	Not a usable combination for structure generation.
W2P1S10	27 Tex Polyester (Black), 27 Tex Polyester (White), 60/2nm Silk (blue) & Wool U/K Count (Fluro Yellow)	Cord Pleat (Plain) – using plan but no 'active' yarn	W11.1" x H10.8"	Pressed with medium iron	W11.1" x H10.8"	Not applicable	• Strong graphic effect within clean, compact and defined cloth.	• Exceptionally light, soft and smooth cloth with excellent drape.	Demonstrates the use of a functional threading for decorative effect.
W2P2S1	27 Tex Polyester (Black) & Lycra (Black)	Cord Pleat (Plain)	W9.5" x H5.75"	Steam Bed	W4.25" x H5.75"	55%	• Effective self-fold pleat with consistent and attractive textural surface.	• Light springy stretch. • Soft draping fabric. • Not a full return to pleat after stretch.	Aesthetically pleasing and usable surface disruption.
W2P2S2	50s Linen (Ecru) & Lycra (Black)	Cord Pleat (Plain)	W10.125" x H5.5"	Steam Bed	W3.75" x H5.5"	63%	• Effective self-fold pleat.	• Light and compact cloth with slightly rough surface.	Potential use for more complex folding.
W2P2S3	2/16ne Mercerised Cotton (Grey) Lycra (Black)	Cord Pleat (Plain)	W10" x H5.625"	Steam Bed	W3.875" x H5.625"	61%	• Effective self-fold pleat. • Some tracking.	• Slightly bulkier and springy cloth.	Potential use for more complex folding.
W2P2S4	27 Tex Polyester (Black) & 52/2 High Twist Wool – S (Ecru)	Cord Pleat (Plain)	Finished without measuring in error.	Machine Wash - Wool Cycle - 40 - 800 spin	W3.75" x H5.5"	Unknown	• Strong neat pleating with a sharp edge – good spring back.	• Not strong enough to self pleat – pressing needed. • Lightweight, bulk free cloth.	Good pleating potential – perhaps not stiff enough for complex folding.
W2P2S5	50s Linen (Ecru) & 52/2 High Twist Wool – S (Ecru)	Cord Pleat (Plain)	Finished without measuring in error.	Machine Wash - Wool Cycle - 40 - 800 spin	W9" x H6"	Unknown	• Full fabric shrink – small amount of float manipulation. • Some tracking.	• Slightly coarse but compact fabric.	Not a usable combination for structure generation.
W2P2S6	2/16ne Mercerised Cotton (Grey) & 52/2 High Twist Wool – S (Ecru)	Cord Pleat (Plain)	Finished without measuring in error.	Machine Wash - Wool Cycle - 40 - 800 spin	W3.2" x H5.75"	Unknown	• Strong neat pleat with 3D form and springiness – good spring back	• Soft to the touch and bouncy cloth. • Robust but soft cloth.	Potential use for more complex folding.
W2P2S7	27 Tex Polyester (Black) & 5x85 Den Silk & 12% Elastomer (Ecru)	Cord Pleat (Plain)	W11.75" x H5.5"	Steam Bed	W5.75" x H5.5"	51%	• Full fabric rather than float focused shrinking.	• Shrink is uncontrolled. • Yarn gives very rough surface.	

Hand Weaving Warp #3: Clasped Weft, Panelling and Thick & Thin Pleating Testing (AVL Dobby)

Warp Set-up	Yarn	2/16ne Mercerised Cotton	EPI	28	Sett	28	Reed	14s	Ends Per Dent	2	Draft	Straight - Block	Shafts	16	Total Ends	364

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage (%)	Effect(s)	Yarn Comments	General Comments
W3P1S0	2/16ne Mercerised Cotton (silver) & 60/2 Silk (khaki) (bundled)	Plain weave & catching in	W12.75" x H5.5"	Press & steam with medium iron	W12.75" x H5.5"	Not applicable	• Contrasting & shaped panelling – not enough contrast between fabric weights	• Yarn combinations do not result in significant difference in handle.	• Catching-in technique effective for creating shaped panels.
W3P1S1	27 Tex Polyester (black) (single & bundled)	Plain weave & catching in	W12" x H4.5"	Press & steam with medium iron	W12" x H4.5"	Not applicable	• Contrasting & shaped panelling – not enough contrast between fabric weights	• Polyester gives effective light handle and soft drape. • Bundled polyester does not give a stiff enough handle.	• Use of a fine polyester warp (rather than cotton) could help to improve panel/base cloth contrast.
W3P1S2	2/16ne Mercerised Cotton (silver) & Linen 9.6/2nm (dark grey) (bundled)	Plain weave & catching in	W12.5" x H4.25"	Press & steam with medium iron	W12.5" x H4.25"	Not applicable	• Contrasting & shaped panelling – not enough contrast between fabric weights.	• Linen provides a stiff cloth that inhibits drape. • Cotton gives defined stable cloth but with rough handle.	• Closest to intended effect – contrast could be improved by using a softer base cloth.
W3P1S3	2/16ne Mercerised Cotton (silver) (single) & 2/21nm Wool (charcoal) (bundled)	Plain weave & catching in	W12.25" x H4.5"	Press & steam with medium iron	W12.25" x H4.5"	Not applicable	• Contrasting & shaped panelling – not enough contrast between fabric weights.	• Wool gives a softer spongier surface but does not have the required rigidity.	• Could felting the wool resulting in a stiffer cloth to create the desired contrast?

Hand Weaving Warp #3: Clasped Weaft, Panelling and Thick & Thin Pleating Testing (AVL Dobby)

Warp Set-up	Yarn	2/16ne Mercerised Cotton	EPI	28	Sett	28	Reed	14s	Ends Per Dent	2	Draft	Straight - Block	Shafts	16	Total Ends	364

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage (%)	Effect(s)	Yarn Comments	General Comments
W3P1S4	27 Tex Polyester (single) (white) & (bundled) (black)	Plain weave alternate stripes	W12" x H4.5"	Press & steam with medium iron	W12" x H4.5"	Not applicable	Contrasting stripes of thick and fine cloth - not enough contrast between fabric weights.	Difference in fabric weight but little difference in level of flexibility.	Yarn combination not suited to desired effect – no further development.
W3P1S5	60/2 Silk (ecru) & 60/2nm Silk & Steel (ecru)	Plain weave alternate stripes	W12" x H5"	Press & steam with medium iron	W12" x H5"	Not applicable	Contrasting stripes - not enough contrast between fabric weights.	Silk/steel introduces a different handle but is not stiff enough for this purpose.	Yarn combination not suited to desired effect – no further development.
W3P1S6	2/16ne Mercerised Cotton (single) (silver) & (bundled) (silver)	Plain weave alternate stripes	W13" x H4.75"	Press & steam with medium iron	W13" x H4.75"	Not applicable	Contrasting weights achieved – fabric folds more readily between rather than between stripes.	• Fine and bundled cotton results in significantly different fabric weights. The cotton gives a rough handle throughout – limiting application.	• Could a softer warp be used to improve handle?
W3P1S7	2/16ne Mercerised Cotton (silver) & Lycra (Black)	Plain weave pleat using bundled warp yarns (60/2 silk)	W11.75" x H5.5"	Steamed on bed	W11.1" x H5.5"	6%	Self pleat effect not achieved.	• Lycra movement results in mild tracking. • Light stretch achieved.	• Possibility of effective pleating with pressing.
W3P1S8	2/16ne Mercerised Cotton (silver) & 52/2 High Twist Wool (Ecru)	Plain weave pleat using bundled warp yarns (60/2 silk)	W12" x H5.5"	Machine Wash - Wool Cycle - 40 - 800 spin	W11.6 x H5.5"	7%	Self pleat effect not achieved.	• Slight shrinkage achieved across the full width of the cloth.	• Possible aesthetic rather than functional effect achieved.
W3P1S9	2/16ne Mercerised Cotton (silver) & 60/2nm Shrink Polyester (white)	Plain weave pleat using bundled warp yarns ((60/2 silk)	W12" x H5.5"	Steamed on bed	W10.6" x H5.5"	12%	Self pleat effect not achieved.	• Shrinkage achieved across the cloth resulting in an effective bubbled surface effect.	• Combination of shrinking and bubbled effect could be used both decoratively and functionally.
W3P1S10	2/16ne Mercerised Cotton (silver) & Lycra (Black)	Plain weave pleat using bundled warp yarns (9.6/2nm linen)	W11.5" x H5.5"	Steamed on bed	W10.8" x H5.5"	6%	Self pleat effect not achieved – small amount of backwards and forwards movement.	• Combination results in some mild texturing and tracking.	• Yarn combination not suited to desired effect – no further development. • Potential for bundled linen to be used for supportive structures.
W3P1S11	2/16ne Mercerised Cotton (silver) & 52/2 High Twist Wool (Ecru)	Plain weave pleat using bundled warp yarns (9.6/2nm linen)	W12" x H6"	Machine Wash - Wool Cycle - 40 - 800 spin	W11.6" x H6"	7%	Self pleat effect not achieved.	• Yarn combination results in a rough handle and untidy appearance.	• Yarn combination not suited to desired effect – no further development.
W3P1S12	2/16ne Mercerised Cotton (silver) & 60/2nm Shrink Polyester (white)	Plain weave pleat using bundled warp yarns (9.6/2nm linen)	W12" x H6"	Steamed on bed	W10.3" x H6"	14%	Self pleat effect not achieved – small amount of backwards and forwards movement.	• Shrinkage achieved across the cloth resulting in an effective bubbled surface effect.	• Yarn combination not suited to desired effect – no further development.
W3P1S13	30/2nm Feltable lambswool (silver)	Plain weave	W12.25" x H5"	Machine Wash - Wool Cycle - 60 - 800 spin then at 90	W11.6" x H4.5"	W - 5% H – 10%	• Limited width reduction. Mild tracking across the cloth.	• Gives the surface of the cloth a fluffiness which is slightly rough to the touch. • Felting not achieved – inhibited by plain weave.	• Weft yarn to be tested with alternative structures and a finer warp to encourage felting. • Potential for wool to be used to give body to folding fabrics.
W3P1S14	2/16wc Worsted Wool (black)	Plain weave	W12.5" x H4.5"	Machine Wash - Wool Cycle - 60 - 800 spin then at 90	W12.5" x H4.5"	0%	• No width reduction. • Mild tracking across the cloth.	• Felting not achieved – possibly inhibited by plain weave. • The wool gives a coarse surface in combination with plan weave.	• No further development at this stage. • Could be a second choice for a base cloth for a folding fabric.
W3P1S15	30/1nm Japanese High Twist Wool – S (black) & 2/21nm Wool (charcoal) (bundled)	Plain weave & catching in	W12.25" x H5.25"	Machine Wash - Wool Cycle - 40 - 800 spin	W12" x H5"	2%	• No pleating in central panel. • Mild tracking across the cloth	• Bundled wool results in body but malleability. • Fine wool gives a smooth light cloth.	• Intended effect not achieved further development and testing needed – panel size/ratio and weave structures.
W3P1S16	2/16ne Mercerised Cotton (silver) & 60/2nm Shrink Polyester (white)	Plain weave	W12.25" x H5.25"	Steamed on bed	W10.2" x H5	17%	• Significant and consistent shrinkages achieved across the width of the cloth.	• Combination of active and passive yarns resulting in an effective bubbled surface effect.	• Combination of shrinking and bubbled effect could be used both decoratively and functionally.
W3P2S1	2/16ne Mercerised Cotton (silver) & Lycra (black)	3/1 & 1/3 twills in blocks	W10.75" x H5.5"	Steamed on bed	W8" x H5.5"	26%	• Not the intended folding. • Mild ribbed effect generated, with substantial shrinkage.	• Lycra gives a firm and mild stretch – could be used in shaping.	• Ribbed effect could be used both decoratively and functionally.
W3P2S2	52/2nm High Twist Wool (Ecru)	3/1 & 1/3 twills in blocks	W11.25" x H5.75"	Machine Wash - Wool Cycle - 40 - 800 spin	W4" x H5.75"	65%	• Soft edged pleats with deep ridged effect.	• Light but substantial stretch. • Wool forms boucle effect – surface loops.	• Desired effect achieved but other combinations give a more pleasing aesthetic appearance – no further development.

Hand Weaving Warp #3: Clasped Weft, Panelling and Thick & Thin Pleating Testing (AVL Dobby)

Warp Set-up	Yarn	2/16ne Mercerised Cotton	EPI	28	Sett	28	Reed	14s	Ends Per Dent	2	Draft	Straight - Block	Shafts	16	Total Ends	364

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage (%)	Effect(s)	Yarn Comments	General Comments
W3P2S3	2/16ne Mercerised Cotton (silver) & 60/2nm Shrink Polyester (white)	3/1 & 1/3 twills in blocks	W11.75" x H6"	Steamed on bed	W9.5" x H6"	19%	• Not the intended folding. • Significant shrinkage – flat fabric.	• Polyester gives a consistent shrink across the width. • Cotton gives fullness to the cloth.	• Usable width reduction – for shaping sections or panels without adding bulk.
W3P2S4	30/1nm Japanese High Twist Wool – S (black)	3/1 & 1/3 twills in blocks	W11.5" x H5.75"	Machine Wash - Wool Cycle - 40 - 800 spin	W3.75" xH5.75	67%	• Soft edged pleats with deep ridged effect.	• Light but substantial stretch. • Wool beds in to the cotton to give a smooth defined appearance.	• Effect could be applied to shaping, fitting and facilitating movement.
W3P3S1	2/16ne Mercerised Cotton & Lycra (Black)	3/1 twill & plain weave in blocks	W11" x H5.5"	Steamed on bed	W9.3" x H5.5"	15%	• Not the intended folding. • Significant shrinkage – flat fabric.	• Movement of lycra increases the density of the cloth. • Soft stretch – small amount of extension.	• Effect could be applied to shaping, fitting and comfort stretch. • Evidence of structure inhibiting/controlling movement – paneling potential.
W3P3S2	52/2nm High Twist Wool (Ecru)	3/1 twill & plain weave in blocks	W11.75" x H5.75"	Machine Wash - Wool Cycle - 40 - 800 spin	W6" x H5.75"	49%	• Soft and fluid ridged effect.	• Wool forms boucle effect - surface loops and some tracking. • Soft spring and extension.	• Desired effect achieved but other combinations give a more pleasing aesthetic appearance – no further development.
W3P3S3	2/16ne Mercerised Cotton & 60/2nm Shrink Polyester (white)	3/1 twill & plain weave in blocks	W11.75" x H5.25"	Steamed on bed	W9.8" x H5.25"	16%	• Not the intended folding. • Significant shrinkage – flat fabric.	• Cotton manipulated into slightly textured loops. • Combinations of good drape and body (direction dependent).	• Effect could be applied to shaping and the reduction of width – possibly in panels. • Lycra and wool more suited to focused shrink and manipulation.
W3P3S4	30/1nm Japanese High Twist Wool – S (black)	3/1 twill & plain weave in blocks	W11.75" x H5.5"	Machine Wash - Wool Cycle - 40 - 800 spin	W6" x H5.5"	49%	• Soft and fluid ridged effect.	• Compact surface with no looping. • Soft spring and extension.	• Effect could be applied to shaping, fitting and facilitating movement. • Movement and structure combinations could be exploited for controlled and isolated shaping.
W3P4S1	2/16ne Mercerised Cotton (grey) & 60/2nm Shrink Polyester (white)	Section 1: 3/1 & 1/3 twills in blocks & Section 2: plain weave	W12" x H8.25"	Steamed on bed	W9" x H8.25 (active section)	25%	• Significant shrinkage – flat fabric in active section. • Active section manipulates the inactive section into mild undulations.	• Polyester gives a consistent shrink across the width. • Cotton gives fullness to the cloth.	• Effect could be applied to shaping, fitting and controlling fullness
W3P4S2	Section1: 30/1nm Japanese High Twist Wool – S (black) & 27 Tex polyester (black)	Section 1: 3/1 & 1/3 twills in blocks & Section 2: plain weave	W11.75" x H8"	Machine Wash - Wool Cycle - 40 - 800 spin	W4" x H 8" (active section)	66%	• Soft edged pleats with deep ridged effect in active section causing light undulation in passive sections.	• Light but substantial stretch. • Wool beds in to the cotton to give a smooth defined appearance.	• Effect could be applied to shaping, fitting, facilitating movement and controlling fullness

Hand Weaving Warp #4: Panelling & Pleating Development

Warp Set-up	Yarn	27 Tex Polyester	EPI	40	Sett	36	Reed	2/14	Ends Per Dent	2/3 alternate	Draft	Block	Shafts	16	Total Ends	800

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage (%)	Effect(s)	Yarn Comments	General Comments
W4P1S1	27 Tex Polyester(white) & 60/2nm Shrink Polyester (white)	Plain Weave	W21.5" x H5.75"	Steambed	W16.75" x H5.75	22%	• 3 picks polyester – 1 pick shrink. • Small scale irregular bubbling effect with permanent shrink (width).	• Some movement in cloth as warp slips on shrink polyester picks.	• Potential for application to isolate panels for both decorative and functional effect.
W4P1S2	27 Tex Polyester (white) & 60/2nm Shrink Polyester (white)	Plain Weave	W21.25" x H5.75"	Steambed	W16.75" x H5.75	22%	• 5 picks polyester – 1 pick shrink. • Small scale (but increased) irregular bubbling effect with permanent shrink (width).	• Some movement in cloth as warp slips on shrink polyester picks.	• Potential for application to isolate panels for both decorative and functional effect.

Hand Weaving Warp #4: Panelling & Pleating Development

Warp Set-up	Yarn	27 Tex Polyester	EPI	40	Sett	36	Reed	2/14	Ends Per Dent	2/3 alternate	Draft	Block	Shafts	16	Total Ends	800

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage (%)	Effect(s)	Yarn Comments	General Comments
W4P1S3	27 Tex Polyester (white) & 60/2nm Shrink Polyester (white)	Plain Weave	W21.5" x H5.75"	Steambed	W16.75" x H5.75	22%	• 7 picks polyester – 1 pick shrink • Larger scale bubbling effect with deeper undulations and a permanent shrink (width).	• Some movement in cloth as warp slips on shrink polyester picks.	• Potential for application to isolate panels for both decorative and functional effect.
W4P1S4	27 Tex Polyester (black) & 60/2nm Shrink Polyester (white)	Plain Weave & Catching In	W21.5" x H12.75"	Steambed	W20" x H12.75 - at narrowest point	7%	• Bubbling effect confined to shaped panels with very slight shaping achieved.	• As the individual panels were not measured before finishing it is unclear if the construction has impacted on the level of shrinkage achieved.	• Variation in shrinkage based on length of shrink polyester not significant for effective shaping – needs further development.
W4P1S5	2/16ne Mercerised Cotton (grey) & Viscose Elite Body (white)	Plain Weave & Catching In	W20.75" x H5.75"	Steambed	W18.75" H5.75"	10%	• Comfort stretch central panel, with isolation of 'activity'.	• Light stable and well draping cloth.	• Potential for application with shaped and contoured panels for fit and comfort.
W4P1S6	27 Tex Polyester (black) & 60/2nm Shrink Polyester (white)	Plain Weave & Catching In	W21.5" x H13.75" Triangular panel: W9.25" x H11.25"	Steambed	W19.75" (narrowest point) x H13.75" Triangular panel: W7.25" x H10.5"	21% in panel	• Curved edge shaping, with shrink isolated to the shaped panel.	• Very light and well draping cloth – slight roughness in active section.	• Potential for edge and integral shaping – limited shaping capability due to average 22% yarn shrinkage.
W4P2S1	30/1nm Japanese High Twist Wool (black) & 27 Tex Polyester (black)	Plain Weave & 3/1 – 3/1 Twills in blocks	W21.5" x H7.75"	800 Spin – 60 Degree Wash	W10.25" x H7.75" - at narrowest point	53%	• Different levels of pleating depending on structure used.	• The 'activity' of the wool was not eliminated by the use of plain weave.	• Potential for utilising different levels of pleating for controlled shaping. • Alternative methods of isolating 'activity' are required.
W4P3S1	30/1nm Japanese High Twist Wool (grey) & bundled wool	Plain Weave & 3/1 – 3/1 Twills & Catching In	W21.5" x H4.75"	800 Spin – 60 Degree Wash	W17" x H4.75"	21%	• Varying panel weight. • Pleating inhibited by the weight of the side panels – ripple effect.	• Pleating limited – ripple rather than deep pleat. 'Activity' not strong enough when combined with heavier weight panel.	• Heavy fabric could be utilised in panel construction of passive fabrics. • Stronger 'active' yarn required if combined with heavy cloth.
W4P3S2	30/1nm Japanese High Twist Wool (grey) & 27 Tex Polyester (black)	Plain Weave & 3/1 – 3/1 Twills & Catching In	W21" x H4.75"	800 Spin – 60 Degree Wash	W13.25" x H4.75"	47%	• Strong central pleated section, with isolation of 'activity'.	• Very light well draping cloth with contrasting functional and visual qualities.	• Potential for application with shaped and contoured panels for shaping, fit and comfort.
W4P3S3	27 Tex Polyester (black & white) & Lycra (black)	Plain Weave & 3/1 – 3/1 Twills & Catching In	W19.5" x H5.75"	Steambed	W12" x H5.75"	38%	• Strong central pleated section, with isolation of 'activity'.	• Lycra combined with polyester gives looped and textured effect due to differential shrinkage.	• Potential for application with shaped and contoured panels for shaping, fit and comfort. • 'Activity' possibly strong enough for use with heavier weight panels.
W4P3S5	30/1nm Japanese High Twist Wool (grey) & 32/2nm Merino Wool (charcoal)	Plain Weave & 3/1 – 3/1 Twills & Catching In	W22.5" x H5"	800 Spin – 60 Degree Wash	W12.5" x H5"	45%	• Strong central pleated section, with isolation of 'activity'.	• Wool and polyester combination in central panel results in a very fine and open cloth.	• Technique of catching in and pleating is effective but a more substantial pleated cloth is required.
W4P4S1	30/2nm Felting Lambswool (silver)	2/2 Twill	W21.5" x H5.5"	800 Spin – 60 Degree Wash	W20.5" x H5.5"	5%	• No felting achieved • Soft, compact and malleable cloth.	• Yarn remains separate and distinct.	• Possibly suited as a base for pleating and folding to give body and structure, and for heavier weight paneling.
W4P5S1	30/2nm Felting Lambswool (silver)	3/1 Twill	W21.5" x H5"	800 Spin – 60 Degree Wash	W20.5" x H5.5"	5%	• No felting achieved • Soft, compact and malleable cloth.	• Yarn remains separate and distinct.	• Possibly suited as a base for pleating and folding to give body and structure, and for heavier weight paneling.
W4P6S1	2/16wc Worsted Wool (black)	Hopsack	W21.5" x H5.55"	800 Spin – 60 Degree Wash	W21" x H5.55"	3%	• No felting achieved • Compact, firm and rough cloth.	• Yarn remains separate and distinct.	• No further development at this stage.

Jacquard Power Loom Batch #1: Yarn Testing

Warp Set-up	Yarn	EPI	Sett	Reed	Ends Per Dent	Repeat	No. Repeats	Total Ends
	32/2 Combed Cotton	96/48	96/48	16s	6	1152	3	3544

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage (%)	Effect(s)	Yarn Comments	General Comments
J1P1S1	60/2nm Shrink Polyester (white)	Plain weave – double cloth	Incomplete	Incomplete	Incomplete	Incomplete	• Incomplete	• Not completed – due to compatibility with the loom. • Polyester to be coned with a less slippery yarn	• Direct comparison for plain weave hand-woven sample - W1P1S8
J1P1S2	Viscose Elite Body (white)	Plain weave – double cloth	W31" x H4.5"	Steam bed	W29" x H4.5"	6%	• Smooth, soft and mildly stretchy cloth (comfort stretch)	• No issues with stopping or breaking. • Jumping back once cut at the right side of the loom – creating loops	• Direct comparison for plain weave hand-woven sample - W1P1S13
J1P1S3	52/2nm High Twist Wool – S (ecru)	Plain weave – double cloth	W32.5" x H4"	Machine Wash - Wool Cycle - 40 - 800 spin	W30.5" x H3.5"	W – 6% H – 25%	• Fluid and light rippling/undulation. • Smooth, even and balanced cloth.	• No issues – no breaking or stopping. • Compared to hand woven version there is little movement or shrinkage.	• The density of warp inhibits movement and so a greater effect could be achieved with a more open structure. • Combination could be applied to inhibit movement and shrink in panels.
J1P1S4	Lycra (black) & 27 Tex Polyester (white)	Plain weave – double cloth	Incomplete	Incomplete	Incomplete	Incomplete	• Incomplete	• Not completed – due to compatibility with the loom. • Lycra to be coned with polyester and Solvron.	• Direct comparison for plain weave hand-woven sample - W1P1S18
J1P1S5	27 Tex Polyester (black) & 60/2nm Shrink Polyester (white) – coned together but not twisted	Plain weave – double cloth	W32.5" x H2.5"	Steam bed	W26.5" x H2.5"	18%	• A good level of shrinkage creating a slightly textured and very slightly rippled cloth. • Stable and compact fabric.	• No issues with stopping or breaking • Small amount of looping coming through accumulator with yarns twisting together slightly • Small loops in polyester in the cloth.	• To give an indication of shrink polyester would be accepted by the loom with another yarn – waiting for delivery of dissolving yarn.

Jacquard Power Loom Batch #1: Structure Testing

Warp Set-up	Yarn	EPI	Sett	Reed	Ends Per Dent	Repeat	No. Repeats	Total Ends
	32/2 Combed Cotton	96/48	96/48	16s	6	1152	3	3544

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage (%)	Effect(s)	Yarn Comments	General Comments
J1P2S1	27 Tex Polyester (black) & 30/2nm Felting Wool (silver)	Knife Pleat – 1 inch/ 0.5 inch – double cloth plain weave & floats	W32.25" x H3"	Machine Wash - Wool Cycle - 60 - 800 spin then at 90	W31" x H3"	4%	• Ridges created with some forward and backwards movement of the panels.	• No issues with the yarn in weaving. • Felting not achieved even at 90 degrees	• Test on a larger scale to assess if pleating effect is improved. • To test wool with a longer float structure to encourage felting.
J1P3S1	32/2 Combed Cotton (ecru) & 27 Tex Polyester (black)	3D Folding – Translation Motif – double cloth plain weave & floats	W32.25" x H6"	Edge finishing only – zigzag stitch	Not applicable	Not applicable	• Pattern significantly elongated from intended design. • Placement and positioning of floats correct.	• Completed without 'active' yarns to test scale of structure	• Motif significantly extended – needs to be reduced by 50%
J1P3S2	32/2 Combed Cotton (ecru) & 1/14nm 100% Lambswool (grey/white)	3D Folding – Translation Motif – double cloth plain weave & floats	W32.5" x 2"	Edge finishing only – zigzag stitch	Not applicable	Not applicable	• Effective pattern scale – but not finished to shrink/ felt.	• Lambswool was too thick and was not being cut effectively by the loom leading to backing up.	• Yarn incompatible – no further development.
J1P4S1	32/2 Combed Cotton (ecru) & 27 Tex Polyester (black)	3D Folding – Multiple V Pattern – double cloth plain weave & floats	W32.25" x H7"	Edge finishing only – zigzag stitch	Not applicable	Not applicable	• Pattern significantly elongated from intended design. • Placement and positioning of floats correct.	• Completed without 'active' yarns to test scale of structure	• Motif significantly extended – needs to be reduced by 50%
J1P4S2	32/2 Combed Cotton (ecru) & 52/2nm High Twist Wool (black)	3D Folding – Multiple V Pattern – double cloth plain weave & floats	W32.5" x 18"	Machine Wash - Wool Cycle - 40 - 800 spin	W28" x H16"	W – 14% H – 11%	• Floats manipulate the surface of the cloth into ridges rather than 3D form • Longer floats forming loops on the surface which limits the manipulation of the cloth	• Some slackening & breaking of wool • Jumping back once cut on the right side of the loom – creating loops	• Flaw appearing in yarn alternation – no issue with digital design • Reduction of float length required.

Jacquard Power Loom Batch #2: Technical Testing – Yarns and Structures

Warp Set-up	Yarn	EPI	Sett	Reed	Ends Per Dent	Repeat	No. Repeats	Total Ends
	32/2 Combed Cotton	96/48	96/48	16s	6	1152	3	3544

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage (%)	Effect(s)	Yarn Comments	General Comments
J2P5S1	27 Tex Polyester (two colours)	3D Folding – Translation Motif (1") – Shibori	W16.5" x H13"	Not finished	W16.5" x H13"	Not applicable	• Sample not finished	• Sample not finished	• Sample not finished due to findings from sample J2P5S2
J2P5S2	27 Tex Polyester (two colours)	3D Folding – Translation Motif (2") – Shibori	W16.5" x H14"	Gather & iron	Not applicable	Not applicable	• Weak, inaccurate and non-distinct folding.	• Not applicable	• To consider: is this a viable method of shaping due to time consuming nature of Shibori gathering?
J2P5S3	27 Tex Polyester (silver & orange)	3D Folding – Translation Motif (1") – Shibori – 4x4 basket base (double cloth)	W37.25" x H11.5"	Not finished	Not applicable	Not applicable	• Sample not finished • Unstable base cloth with long floats & flaws	• Not applicable	• No further development • Use of single rather than double cloth may result in a more suitable base cloth
J2P5S4	27 Tex Polyester (two colours)	3D Folding – Translation Motif (1") – Shibori – 4x4 basket base	W37.25" x H11.5"	Not finished	Not applicable	Not applicable	• Sample not finished	• Sample not finished	• Base cloth unsuitable to 3D folding due to instability and openness.
J2P5S5	27 Tex Polyester (two colours)	3D Folding – Translation Motif (2") – Shibori – 3x3 basket base with extra weft	Not measured in error	Gather & iron	Not applicable	Not applicable	• Weak, inaccurate and non-distinct folding. • Weight of cloth gives body and support.	Not applicable	• To consider: is this a viable method of shaping due to time consuming nature of Shibori gathering?
J2P6S1	27 Tex Polyester (two colours)	3D Folding – Multiple V pattern (1") – Shibori	W13.5" x H11"	Not finished	Not applicable	Not applicable	• Sample not finished	• Sample not finished	• Sample not finished due to findings from sample J2P5S2
J2P6S2	27 Tex Polyester (two colours)	3D Folding – Multiple V pattern (2") – Shibori	W16" x H12"	Not finished	Not applicable	Not applicable	• Sample not finished	• Sample not finished	• Sample not finished due to findings from sample J2P5S2
J2P6S3	27 Tex Polyester (two colours)	3D Folding – Multiple V pattern (1") – Shibori – 4x4 basket base with extra weft	W 32.25" x H7.75"	Not finished	Not applicable	Not applicable	• Sample not finished	• Sample not finished	• Sample not finished due to findings from sample J2P5S5
J2P6S4	27 Tex Polyester (two colours)	3D Folding – Multiple V pattern (2") – Shibori – 3x3 basket base with extra weft						• Sample not completed due to yarn shortage and similarity to next sample	• Not completed
J2P6S5	27 Tex Polyester (two colours)	3D Folding – Multiple V pattern (2") – Shibori & plain panels – 3x3 basket base with extra weft	W32.75" x H7.75"	Not finished	Not applicable	Not applicable	• Sample not finished	• Sample not finished	• Sample not finished due to findings from sample J2P5S5
J2P7S1	30/2nm Felting Wool (silver)	Hopsack & 1/3 Twill	W10.6" x H4.6"	Machine Wash - Fastwash - 30 - 800 spin	W.10.5" x H4"	W1% x H13%	• Dense solid cloth	• No felting occurred	• No further development – yarn not compatible with Jacquard loom
J2P7S2	30/2nm Felting Wool (silver)	1/5 Twill & 1/7 Twill	W10.6" x H3.5"	Machine Wash - Fastwash - 30 - 800 spin	W10.3" x H2.8"	W3% x H20%	• Dense solid cloth • Flaws in fabric due to looping of weft		
J2P8S1	27 Tex Polyester & 60/1nm Shrink Polyester (Solvron Core)	1/3 & 3/1 Twill Blocks – Double Cloth						• Sample not completed due to yarn compatibility – see sample J2P8S4	• Not completed
J2P8S2	27 Tex Polyester & Lycra (Solvron Core)	1/3 & 3/1 Twill Blocks – Double Cloth						• Sample not completed due to yarn compatibility – see sample J2P8S4	• Not completed
J2P8S3	27 Tex Polyester & Grilon	1/3 & 3/1 Twill Blocks – Double Cloth	W32.8" x H2"	Not finished	Not applicable			• Yarn too slippery and not compatible with loom/accumulator.	• Sample abandoned

Jacquard Power Loom Batch #2: Technical Testing

Warp Set-up	Yarn	EPI	Sett	Reed	Ends Per Dent	Repeat	No. Repeats	Total Ends
	32/2 Combed Cotton	96/48	96/48	16s	6	1152	3	3544

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage (%)	Effect(s)	Yarn Comments	General Comments
J2P8S4	27 Tex Polyester & Solvron (white)	1/3 & 3/1 Twill Blocks – Double Cloth	W32.8" x H2"	Not finished	Not applicable	Not applicable		• Yarn too slippery and not compatible with loom/accumulator.	• Sample abandoned

Jacquard Power Loom Batch #2: Technical Testing

Warp Set-up	Yarn	32/2 Combed Cotton	EPI	96/48	Sett	96/48	Reed	16s	Ends Per Dent	6	Repeat	1152	No. Repeats	3	Total Ends	3544

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage (%)	Effect(s)	Yarn Comments	General Comments
J2P9S1	27 Tex Polyester (white)	3, 5 & 7 end Huck Lace & Mock Leno	3 End Huck Lace - W5.5" x H5.5"	Machine Wash - Fastwash - 30 - 800 spin	3 End Huck Lace - W5.5" x H5"	W0% x H9%	• Dense & compact structures with varying float length – no opening up achieved on finishing Lightweight with little bulk	• Cotton provides a small amount of give in the warp direction	• Warp too dense to allow the lace structures to open up – EPI reduction required
			5 End Huck Lace - W5.6" x H5.75"		5 End Huck Lace - W5.6" x H5.25"	W0% x H9%			
			7 End Huck Lace - W5.6" x H5.6"		7 End Huck Lace - W5.6" x H5.25"	W0% x H6%			
			Mock Leno - W5.1 " x H5.75"		Mock Leno - W5.1 " x H5.25"	W0% x H9%			
J2P10S1	27 Tex Polyester (white)	5, 7, 13, 31 Float Waffle	5 End Float Waffle - W5.4" x H5.5"	Machine Wash - Fastwash - 30 - 800 spin	5 End Float Waffle - W5.25" x H5"	W3% x H9%	• Semi- 3D ribbed effect Slight give in warp direction	• Cotton warp resulted in some height shrinkage • Polyester remained consistent	• Potential for movement and structure to be used for functional application & shaping. • Could weft shrink & give be achieved using alternative weft yarn?
			7 End Float Waffle - W5.75 x H5.5"		7 End Float Waffle - W5.75 x H4.5"	W0% x H19%	• 3D rib and wavy float effect • Springy extension in warp direction Some bulk & thickness	• Cotton warp resulted in height shrinkage & extension • Polyester remained consistent	
			13 End Float Waffle - W5.4" x H5.25"		13 End Float Waffle - W5.25" x H3.4"	W3% x H38%	• Deep cellular structure • Stretch in warp direction Some bulk & thickness	• Cotton warp resulted in height shrinkage & stretch • Polyester remained consistent	
			32 End Float Waffle - W5" x H5.5"		32 End Float Waffle - W5" x H3.25"	W0% x H41%	• Deep cellular structure • Stretch in warp direction Some bulk & thickness	• Cotton warp resulted in height shrinkage & stretch • Polyester remained consistent	
J2P11S1	52/2nm High Twist Wool (black)	1/7 and 7/1 Twill – 1 inch - vertical blocks – warp/weft-faced pleating	W16" x H5"	Machine Wash - Fastwash - 30 - 800 spin	W14.5" x H4"	W10% x H20%	• Slight irregular creasing rather than pleating Small amount of give in warp & weft direction	• In combination with the density of the warp, the high twist wool's activity is diminished	• No functional application in current state – could reduce EPI to encourage pleating • Strong visual effects created – to be developed •
J2P12S1	52/2nm High Twist Wool (black)	1/7 and 7/1 Twill – 0.5 inch - vertical blocks – warp/weft-faced pleating	W16" x H5.7"	Machine Wash - Fastwash - 30 - 800 spin	W14" x H4.75"	W12% x H17%	• Slight irregular creasing rather than pleating Small amount of give in warp & weft direction		
J2P13S1	52/2nm High Twist Wool (black)	1/7 and 7/1 Twill – 0.5 inch - vertical blocks – warp/weft-faced pleating central panel	W15.25" x H6.7"	Machine Wash - Fastwash - 30 - 800 spin	W13.75" x H6"	W10% x H10%	Twills: • Slight irregular creasing rather than pleating • Small amount of give in warp & weft direction Hopsack: Compact, dense and stable cloth		
J2P14S1	52/2nm High Twist Wool (black)	1/7 and 7/1 Twill – 1 inch - vertical blocks – warp/weft-faced pleating central panel	W15" x H6.4"	Machine Wash - Fastwash - 30 - 800 spin	W14" x H5.75"	W7% x H10%			

Jacquard Power Loom Batch #2: Technical Testing – Yarns and Structures

Warp Set-up	Yarn	32/2 Combed Cotton	EPI	96/48	Sett	96/48	Reed	16s	Ends Per Dent	6	Repeat	1152	No. Repeats	3	Total Ends	3544	

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage (%)	Effect(s)	Yarn Comments	General Comments
J2P15S1	52/2nm High Twist Wool (black) & 27 Tex Polyester (black)	1/7 and 7/1 Twill – 1 inch blocks with inactive stripes	W16" x H9.2"	Machine Wash - Fastwash - 30 - 800 spin	W15" x H7.5"	W6% x H18%	• Ripples and undulation giving 3D textured effect • Small amount of extension in warp & weft direction	• In combination with the density of the warp, the high twist wool's activity is diminished	• No significant functional application in current state – could reduce EPI to encourage pleating • Strong visual effects created – to be developed
J2P16S1	52/2nm High Twist Wool (black)	1/7 and 7/1 Twill, 1/3 and 3/1 Twill – warp/weft-faced pleats	W16" x H9.5"	Machine Wash - Fastwash - 30 - 800 spin	W14.25" x H8.25"	W11% x H13%	1/3 & 3/1 Twills: • Slight irregular creasing rather than pleating • Some extension in weft direction 1/7 & 7/1 Twills: • Slight forward & backwards movement – relief • Dense & compact		• No functional application in current state – could reduce EPI to encourage pleating • Strong visual effects created – to be developed

Jacquard Power Loom Batch #3: Technical Testing – Waffle Structures & Panelling

Warp Set-up	Yarn	32/2 Combed Cotton	EPI	96/48	Sett	96/48	Reed	16s	Ends Per Dent	6	Repeat	1152	No. Repeats	3	Total Ends	3544	

Sample Ref	Weft Yarn (s)	Weave Structure(s)	Unfinished Dimensions	Finishing	Finished Dimensions	Shrinkage (%)	Effect(s)	Yarn Comments	General Comments
J3P6S1	32/2 Combed Cotton	13End Float Waffle – Vertical Triangle Panels	Triangle = W2" x H7.5"	Machine Wash - Fastwash - 30 - 800 spin	Triangle W1.75" x H6.25"	W13% x H17%	• Small amount of shrinkage in waffle panel – not significant enough to shape the cloth	• Cotton warp & weft resulted in some shrinkage & extension	• Decorative or thermoregulatory application only
J3P6S2	32/2 Combed Cotton	13End Float Waffle – Vertical Triangle Panels	Triangle = W2.75" x H5"	Machine Wash - Fastwash - 30 - 800 spin	Triangle = W2.25" x H4.25"	W18% x H15%	• Small amount of shrinkage in waffle panel – not significant enough to shape the cloth	• Cotton warp & weft resulted in some shrinkage & extension	• Decorative or thermoregulatory application only
J3P7S1	32/2 Combed Cotton	13 End Float Waffle – Vertical Stripes with 4x4 Basket	W13" x H10" (1" stripe width)	Machine Wash - Fastwash - 30 - 800 spin	W10.75 x H9"	W17% x H10%	• Small amount of shrinkage in waffle panel – not significant enough to pleat the cloth – some seersucker effect	• Cotton warp & weft resulted in some shrinkage & extension	• Fullness control of the cloth using seersucker effect
J3P7S2	32/2 Combed Cotton	13 End Float Waffle – Horizontal Stripes with 4x4 Basket	Stripe height 2.5"	Machine Wash - Fastwash - 30 - 800 spin	Stripe height 1.75"	H30%	• Small amount of shrinkage in waffle panel – not significant enough to pleat the cloth – no seersucker effect	• Cotton warp & weft resulted in some shrinkage & extension	• Decorative or thermoregulatory application only
J3P8S1	32/2 Combed Cotton	13 End Float Waffle – background & 4x4 Basket circle	Oval/Circle - W5.25" x H10"	Machine Wash - Fastwash - 30 - 800 spin	Oval/Circle - W4.25" x H6.25"	W19% x H37%	• High level of shrinkage in waffle panel resulting in shaping & tapering of the cloth.	• Cotton warp & weft resulted in good shrinkage & extension	• Shaping and tapering of garments • Stretch for comfort & fit
J3P8S2	32/2 Combed Cotton	13 End Float Waffle – circle & 4x4 Basket background	External panel - W10" x H10.5"	Machine Wash - Fastwash - 30 - 800 spin	External panel - W7.5" x H6.25"	W25% x W40%	• High level of shrinkage in waffle panel resulting in shaping & tapering of the cloth.	• Cotton warp & weft resulted in good shrinkage & extension	• Shaping and tapering of garments • Stretch for comfort & fit
J3P9S1	32/2 Combed Cotton	13 End Float Waffle – background & 2x2 Basket circle	Oval/Circle - W5" x H13.5"	Machine Wash - Fastwash - 30 - 800 spin	Oval/Circle - W4.5" x H11.25"	W10% x H17%	• Small amount of shrinkage in waffle panel resulting in shaping & tapering of the cloth.	• Cotton warp & weft resulted in some shrinkage & extension	• Tapering of garments • Stretch for comfort & fit
J3P9S2	32/2 Combed Cotton	13 End Float Waffle – circle & 2x2 Basket background	External panel - W5.5" x H14"	Machine Wash - Fastwash - 30 - 800 spin	External panel - W5" x H13"	W9% x H9%	• Small amount of shrinkage in waffle panel resulting in shaping & tapering of the cloth.	• Cotton warp & weft resulted in some shrinkage & extension	• Tapering of garments • Stretch for comfort & fit

Appendix 6:

Jacquard Yarn Compatability

The following yarns were found to be incompatible with the Jacquard power loom when inserted as a weft yarn

Weft Yarn	Reasons of Yarn/Loom Incompatibility
60/2nm Shrink Polyester	Yarn too slippery and not compatible with loom/ accumulator.
Lycra	Level of stretch in yarn not compatible with loom/ accumulator - looping and slipping
30/2nm Felting Wool (silver)	Wool was too thick and was not being cut effectively by the loom leading to backing up. Flaws in fabric due to looping of weft
1/14nm 100% Lambswool	Lambswool was too thick and was not being cut effectively by the loom leading to backing up.
Solvron (white)	Yarn too slippery and not compatible with loom/ accumulator.

Table A5.1: Weft Yarns Incompatible with the Jacquard Loom

Appendix 7:

MMAQ Residency Proposal

Cut, Colour and Craftsmanship

> [...] pattern seems to have a horror of cutting into the body of the fabric.
>
> (Dalby 1993: 151)

Historically, loom type and cloth width determined the cut of garments. Textiles were a valued commodity meaning that the economic use and reluctance to cut and waste fabric was the norm. Mass production, and more recently, the rise of fast fashion have resulted in the devaluing of textiles – it is now a throwaway commodity. However, the respect for material remains central in Japanese design today.

One of the exciting and inspirational things about Japanese design is its seamless juxtaposition of tradition and innovation – of craftsmanship and technology. Function and simplicity are integral both to the quality and the aesthetic of design. "There is a traditional Japanese aesthetic that sees the utmost richness in what is extremely plain... an infinite flexibility that accepts each and every concept and adjusts to any purpose." (Hara in Pollock 2012: 11).

The Japanese kimono is synonymous with craftsmanship and tradition; with its zero-waste, minimal-cut construction it provides the perfect canvas to communicate the value of textiles – to reignite the "horror" of discarding and wasting textiles in contemporary society. During the residency a series of contemporary handcrafted kimonos will be produced, with individual bolts of cloth designed and woven for specific traditional

Kimono constructions; engineering the pattern to complement (and even enhance) the garment shape – to flatter, to accentuate, to create impact, to communicate. The concept builds upon my PhD research into constructing garments shaped on and wearable from the loom, by exploring the creative and aesthetic rather than technical possibilities of designing a textile engineered for a particular garment.

Furthermore, the residency and its outcomes will explore notions of gender and genderlessness in contemporary textiles and fashion. Increasingly, fashion designers are questioning and challenging notions of gender and beauty through garment silhouettes, types and construction on the catwalk, as well as by producing androgynous and unisex commercial collections. The minimalism and genderless nature of the kimono's cut facilitates the investigation of the role that textiles play in the gendering of garments. During the residency I will explore the design of genderless textiles, and their application to unisex kimono jackets, with the versatility of garments extending their wearability and use, and increasing their use value.

The proposed residency would require the use of both a hand loom and computer aided Jacquard loom to construct the textiles, as well as the use of the computer lab for design development and sewing room for garment construction. The project duration would be eight weeks, with six weeks being dedicated to textile design and production, and a further two weeks for garment construction.

Appendix 8

Weave Structure Tension Compatability

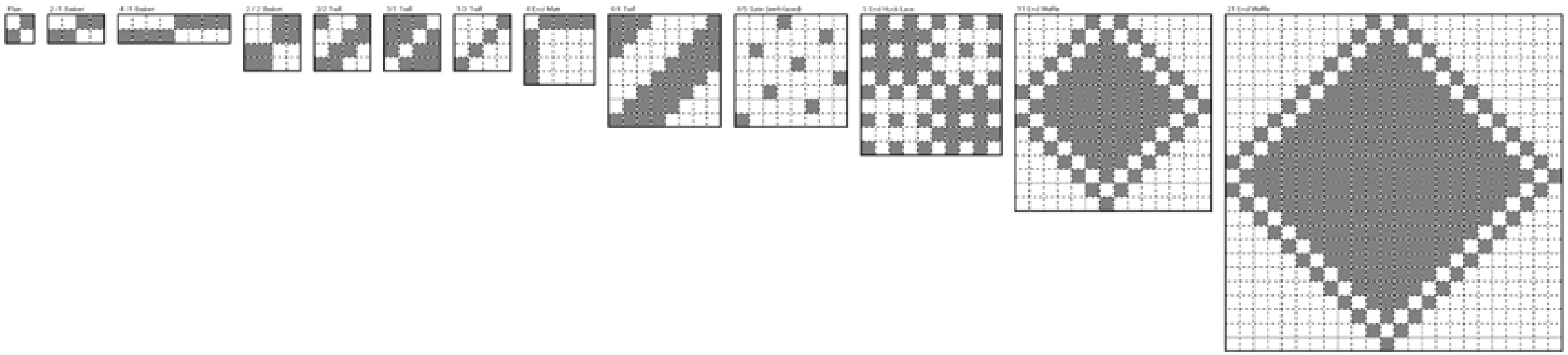
The weave structure combinations detailed below are from sections of the prototype garment lay-plans. The structures when woven simultaneously, result in multiple tensions and rates of fabric build-up across the width of the warp. Significant differences in tension impact negatively on fabric quality and garment dimensions. When working with the Jacquard Power loom tension differentials can also result in the loom stopping. As such, a number of weave structure combinations have been found to be incompatible.

Loom and Weaving Set-up						Single Cloth Structures										Double Cloth Structures									
Garment	Loom	Warp Yarn	Weft Yarn	Ends Per Inch	Pick Rate	Plain	8/5 Satin (Weft-facing)	21 End Waffle	11 End Waffle	2/2 Twill	4/4 Twill	4 End Matt	4/1 Basket (Irregular)	2/1 Basket (Irregular)	5 End Huck Lace	Plain	11 End Waffle	2/2 Twill	1/3 Twill	3/1 Twill	4/4 Twill	5 End Huck Lace	2/2 Basket	5 End Huck Lace	Compatible
Trousers	Jacquard	30/2ne Combed Cotton	30/2ne Combed Cotton	96/48 EPI	50 PPI			✓		✓															No
Trousers	Jacquard	30/2ne Combed Cotton	30/2ne Combed Cotton	96/48 EPI	60 PPI			✓		✓															No
Trousers	Jacquard	30/2ne Combed Cotton	30/2ne Combed Cotton	96/48 EPI	50 PPI					✓							✓								Yes
Trousers	Jacquard	30/2ne Combed Cotton	30/2ne Combed Cotton	96/48 EPI	50 PPI														✓	✓	✓		✓	✓	Yes
T-shirt	Dobby	6/30ne, 2/16ne Combed Cotton	6/30ne, 2/16ne Combed Cotton	18 EPI	18 EPI	✓									✓										Yes
Dress	Jacquard	30/2ne Combed Cotton	30/2ne Combed Cotton	96 EPI	50 PPI		✓				✓														Yes
Dress	Jacquard	30/2ne Combed Cotton	30/2ne Combed Cotton	96 EPI	50 PPI		✓	✓																	Yes
Jacket*	Dobby	27 Text Polyester	27 Tex Polyester	96 EPI	16 PPI	✓									✓										Yes
Top	TC2	30/2ne Combed Cotton	30/2ne Combed Cotton	90/45 EPI	45 PPI				✓	✓						✓		✓	✓	✓				✓	Yes
Top	TC2	30/2ne Combed Cotton	30/2ne Combed Cotton	90/45 EPI	45 PPI				✓	✓						✓	✓	✓							Yes
Top	TC2	30/2ne Combed Cotton	30/2ne Combed Cotton	90/45 EPI	45 PPI											✓	✓				✓			✓	Yes
Coat**	TC2	30/2ne Combed Cotton	6/30ne Combed Cotton	90/45 EPI	14 PPI					✓		✓	✓	✓		✓									No
Coat**	TC2	30/2ne Combed Cotton	6/30ne Combed Cotton	90/45 EPI	16 PPI					✓		✓	✓	✓		✓									No
Coat**	TC2	30/2ne Combed Cotton	6/30ne Combed Cotton	90/45 EPI	20 PPI					✓		✓	✓	✓		✓									No

* Jacket warp was threaded with 2 ends per heddle and the weft yarn was 6x strands of 27 Tex Polyester. The garment was woven as plain weave.

** Coat weft yarn was 3 x strands of 6/30ne Cotton. The double cloth sections were quilted during construction using waste during.

Weave Structures Used



List of References

List of References

AAKKO, M. & NIININIMAKI, K. (2013). 'Experimenting with Zero-waste Fashion Design'. In: NIINAMKI, K. (Ed). (2013). *Sustainable Fashion: New Approaches*. Helsinki: Aalto University. pp. 68-79. Available at: https://shop.aalto.fi/media/attachments/1ee80/SustainableFashion.pdf Accessed: 12 July 2018.

ABBOTT, A. (2004). *Methods of Discovery: Heuristics for the Social Sciences*. London: W.W. Norton & Company Ltd.

ABERNATHY, F, H. DUNLOP, J, T. HAMMOND, J, H. & WEIL, F. (1999). A *Stitch in Time: Lean Retailing and the Transformation of Manufacturing - Lessons From the Apparel and Textile Industries*. Oxford: Oxford University Press.

ALBERS, A. (2000). *Anni Albers: Selected Writings on Design*. Hanover: University Press of New England.

ALBERS, A. (1961). *Albers: On Designing. Connecticut*: Wesleyan University Press.

ALDERMAN, S. (2008). *Mastering Weave Structures: Transforming Ideas into Great Cloth*. Loveland: Interweave Press Inc.

ALDRICH, W. (2008). *Metric Pattern Cutting for Women's Wear*. (5th Edition). Oxford: John Wiley & Sons.

ALLWOOD, J, M. BOCKEN, N. LAURSEN, S, E. & DE RODRIGUEZ, C, M. (2006). *Well Dressed?: The Present and Future Sustainability of Clothing and Textiles in the United Kingdom*. Cambridge: Institute for Manufacturing.

ANDERSEN, K, S. (2005). 'Seamless Textiles with Inherent Shape'. (PhD Thesis) North Carolina: North Carolina State University. Available at: http://repository.lib.ncsu.edu/ir/handle/1840.16/3810. Accessed: 01 August 2014.

ASHDOWN, S, P. (2011). 'Improving Body Movement Comfort in Apparel'. In: SONG, G. (Ed.). *Improving Comfort in Clothing*. Cambridge: Woodhead Publishing. pp.278–302.

ASPINALL, M. (2012). 'Design That Looks at Models from History and Nature'. *Textile Tool Box*. Available at: http://www.textiletoolbox.com/research-writing/design-look-models-history-and-nature/. Accessed: 09 November 2018.

AU, J, S. TAYLOR, G. & NEWTON E, W. (2003). 'Grounded Design Theory of Japanese Fashion Designers'. *The Design Journal*. 6(3). pp.3-23.

AUCH, M. (c.2017). 'Monika Auch, Visual Artist: Profile'. *Monika Auch*. Available at: http://www.monikaauch.nl/. Accessed: 05 January 2018.

AUCH, M. (2016). 'The Intelligence of the Hand'. In: NIMKULRAT, N. KANE, F. & WALTON, K. (Eds.). (2016). *Crafting Textile in the Digital Age*. London: Bloomsbury. pp. 61-73.

AUGUST. (2011). 'August Fashion'. *August Fashion*. Available at: http://august.synthasite.com/. Accessed: 03 January 2014.

BANG, A, L. (2010). 'Emotional Value of Applied Textiles: Dialogue-oriented and Participatory Approaches to Textile Design'. (PhD Thesis). Kolding: Design School Kolding.

BARRETT, E. (2007). 'Studio Enquiry and New Frontiers of Research'. *Studies in Material Thinking* .1(1). pp.1–3. Available at: https://www.materialthinking.org/sites/default/files/papers/Estelle.pdf. Accessed: 29 September 2016.

BARTLETT, D. (2000). 'Issey Miyake: Making Things'. *Fashion Theory: The Journal of Dress*. 4(2). pp. 223–227.

BATH SPA UNIVERSITY. (c.2016). 'Tim Parry Williams Profile'. *Bath Spa University.* Available at: https://www.bathspa.ac.uk/our-people/tim-parry-williams/. Accessed: 05 January 2018.

BENAIM, L. (1997). *Fashion Memoir: Issey Miyake*. London: Thames & Hudson.

BEHERA, B, K. & MISHRA, R. (2008). '3-Dimensional Weaving'. *Indian Journal of Fibre & Textile Research*. 33. pp. 274–287.

BHARDWAJ, V. & FAIRHURST, A. (2010). 'Fast Fashion: Response to Changes in the Fashion Industry'. *The International Review of Retail, Distribution and Consumer Research*. 20(1). pp. 165-173. DOI: 10.1080/09593960903498300.

BLACK, S. (2008). Eco-Chic: The Fashion Paradox. London: Black Dog.

BILISIK, K. (2012). 'Multiaxis Three-Dimensional Weaving for Composites: A Review'. *Textile Research Journal*. 82(7). pp. 725–743.

BRACKENBURY, T. (1992). *Knitted Clothing Technology*. London: BSP Professional.

BRADDOCK CLARKE, S, E. & HARRIS, J. (2012). *Digital Visions for Fashion + Textiles: Made in Code*. London: Thames and Hudson Ltd.

BRAITHWAITE, N. (2017). 'Sensing Creativity: The Role of Materials in Shoe Design'. *The Senses and Society*. 12(1). pp. 90-94.

BRAMALL, S. (2005). 'Key Trends in Sportswear Design'. In: SHISHOO, R. (Ed.). (2005). *Textiles in Sport*. Cambridge: Woodhead Publishing in Textiles. pp. 25-43.

BRAUNGART, M. & McDONOUGH, W. (2009). *Cradle to Cradle: Remaking the Way We Make Things*. London: Vintage.

BRIGGS-GOODE, A. & TOWNSEND, K. (Eds.). (2011). *Textile Design: Principles, Advances and Applications*. Oxford: Woodhead Publishing.

BROWN, S. & MCQUAID, M. (2016). *Scraps: Fashion, Textiles, and Creative Reuse*. New York: Cooper Hewitt

BROWN, S. (2013a). 'Design for Cyclability: Pre-Consumer Waste'. *Textile Toolbox*. Available at: http://www.textiletoolbox.com/posts/pre-consumer-waste/. Accessed: 04 December 2014.

BROWN, S. (2013b). 'Design for Cyclability: Post Consumer Waste'. *Textile Toolbox* Available at: http://www.textiletoolbox.com/posts/post-consumer-waste/. Accessed: 04 December 2014.

BURNHAM, D, K. (1973). *Cut My Cote*. Toronto: Royal Ontario Museum.

CAMPBELL, J, R. (2016). 'Forward'. In: NIMKULRAT, N. KANE, F. & WALTON, K. (Eds.). (2016). *Crafting Textile in the Digital Age*. London: Bloomsbury. pp. XIX - XXIII.

CARDOSO, R. (2008). 'Craft Versus Design: Moving Beyond a Tired Dichotomy'. In: Adamson, G. (Ed.) *The Craft Reader*. Oxford: Berg. pp. 321–32.

CARRICO, M. & KIM, V. (2014). 'Expanding Zero-Waste Design Practices: A discussion paper'. I*nternational Journal of Fashion Design, Technology and Education*. 7(1). pp. 58 – 64. DOI: 10.1080/17543266.2013.837967.

CHAPMAN, J. (2013). 'Repair'. *Textile Toolbox*. Available at: http://www.textiletoolbox.com/research-writing/repair/. Accessed: 09 November 2018.

CHAPMAN, J. & GANT, N. (Eds). (2007). *Designers, Visionaries and Other Stories: A Collection of Sustainable Design Essays*. London: Earthscan.

CHAUDHARI, S, S. CHITNIS, R, S. & RAMKRISHMAN, R. (2004). 'Waterproof Breathable Active Sports Wear Fabrics'. *Sasmira*. Available at: http://www.sasmira.org/sportwear.pdf. Accessed: 2 July 2015.

CLARK, A. & CHALMERS, D. (1998). 'The Extended Mind'. *Analysis*. 58.1. pp. 7–19.

COLCHESTER, C. (2007). *Textiles Today: A Global Survey of Trends and Traditions*. London: Thames & Hudson.

COOKE, B. (2011). 'The Physical Properties of Weft Knitted Structures' in AU, K. F. (Ed). (2011). *Advances in Knitting Technology*. Cambridge: Woodhead Publishing. pp. 37-47.

COOPER HEWITT. (c.2017). 'Objects Involving Nuno Corporation as Manufacturer'. *Cooper Hewitt, Smithsonian Design Museum*. Available at: https://collection.cooperhewitt.org/people/18045705/ objects/ manufacturer/. Accessed: 29 July 2018.

CORBMAN, B, P. (1983). *Textiles: Fiber to Fabric*. (6th Edition). London: McGraw-Hill.

COS. (c.2017a). 'Creating Ten Years of COS'. *COS*. Available at: https://www.cosstores.com/gb/Studio/Projects/10. Accessed: 28 August 2017.

COS. (c.2017b). 'About COS'. *COS*. Available at: https://www.cosstores.com/gb/. Accessed: 28 August 2017.

CRAFTS COUNCIL. (2016). 'Make:Shift'. *Crafts Council*. Available at: http://www.craftscouncil.org.uk/what-we-do/makeshift/. Accessed: 20 July 2016.

CSIKSZENTMIHALYI, M. & CSIKSZENTMIHALYI, I, S. (1988). *Optimal Experience: Psychological Studies of Flow in Consciousness*. Cambridge: Cambridge University Press.

DA CRUZ, E. (2014). 'Miyake, Kawakubo, and Yamamoto: Japanese Fashion in the Twentieth Century'. *Metropolitan Museum of Art: Heilbrunn Timeline of Art History*. Available at: http://www.metmuseum.org/toah/hd/jafa/hd_jafa.htm. Accessed: 13 March 2015.

DALBY. L. (1993). *Kimono: Fashioning Culture*. New Haven: Yale UP.

DALGAARD, L. (2012). M*agical Materials to Weave: Blending Traditional & Innovative Yarns*. Translated by Ann Richards. Vermont: Trafalgar Square Books.

DANT, T. (2008). The Pragmatics of Material Interaction'. *Journal of Consumer Culture*. 8(1). pp.11–33.

DE FREITAS, N. (2002). 'Towards a Definition of Studio Documentation: Working Tool and Transparent Record'. *Working Papers in Art and Design*. 2. pp. 1–10.

DEFRA UK. (2013a). 'Prevention Is Better than Cure: The Role of Waste Prevention in Moving to a More Resource Efficient Economy'. *The Waste Prevention Team DEFRA*. Available at: https://www.gov.uk/government/policies/reducing- and-managing-waste. Accessed: 03 January 2014.

DEFRA UK. (2013b). 'Waste Prevention Programme for England: Overview of Evidence – A Rationale for Waste Prevention in England'. *The Waste Prevention Team DEFRA*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/264909/wpp-evidence-overview.pdf. Accessed: 03 January 2014.

DE KLEE, K. (2016). 'Friends of Light: Handwoven Jackets From New York'. *Design Indaba.* Available at: http://www.designindaba.com /articles/point-view/friends-light-handwoven-jackets-new-york. Accessed: 27 July 2018.

DEZEEN. 2016. 'Issey Miyake Bakes Fabric to Pleat Spring Summer 2016
Garments, 8th January 2016'. *Deezen*. Available at: http://www.dezeen.com /2016/01/08/spring-summer-2016-fashion-collection-issey-miyake/ Accessed: 13 July 2016.

DEZEEN. 2014. 'Issey Miyake's focus is "being innovative with technology" says head of womenswear, 12th November 2014'. *Dezeen*. Available at: http://www.dezeen.com/2014/11/12/issey-miya ke-yoshiyuki- miyamae-interview-3d-stretch-seam-fashion-technology/. Accessed: 09 September 2015.

DICK, B. (2000) 'A Beginners Guide to Action Research'. *Resources Papers in Action Research*. Available at: http://www.uq.net.au/action_research/arp/guide.html. Accessed: 26 May 2018.

DIGITAL WEAVING NORWAY. (c.2018). 'TC2 Loom'. *Tronrud Engineering*. Available at: http://www.digitalweaving.no/tc2-loom/. Accessed: 25 June 2018.

DION, G. (2013). 'Haute Tech Couture: Digital Fabrication of Wearable Technology' in *Proceedings of the First International Conference on Digital Fashion*. pp. 106–12. London: University of the Arts. 16-17 May 2013.

DOLOUGHAN, F. (2002). 'The Language of Reflective Practice in Art and Design'. *Design Issues*. 18(2). pp. 55–65.

DORMER, P. (1994). *The Art of the Maker: Skill and its Meaning in Art, Craft and Design*. London: Thames & Hudson.

DOSA. (c.2017). 'Life of Jamandi Project'. *Dosa Inc*. Available at: https://dosainc.com/specialprojects/life-of-jamdani. Accessed: 12 July 2018.

DREYFUS, H, L. & DREYFUS, S, E. (1986). *Mind Over Machine: The Power of Human Intuition and Expertise in the Era of the Computer*. Oxford: Basil Blackwell.

DRS. (2016). DRS 2016: 'Design + Research + Society, Future-Focused Thinking'. In: *Proceedings of DRS2016: Design + Research + Society Future-Focused Thinking*. Vol.7 Embodied Making and Learning. pp. 2889-2965.

PIPER, A. (2016). 'Code, Decode, Recode: Constructing, Deconstructing and Reconstructing Knowledge Through Making'. In: *Proceedings of DRS2016: Design + Research + Society Future-Focused Thinking*. Vol.7 Embodied Making and Learning. pp. 2889-2965.

ENGLISH, B. (2011). *Japanese Fashion Designers: The Work and Influence of Issey Miyake, Yohji Yamamoto and Rei Kawakubo*. Oxford: Berg.

FERRIER, M. (2015). 'Forget "Athleisure" – Here's How to Look Chic in a Tracksuit'. *The Guardian*. Available at: http://www.theguardian.com/fashion/2015/mar/10/ athletic-lesiure-sportswear-everyday-fashion-trend-2015. Accessed: 15 May 2015.

FIELD, A. (2008). *Collapse Weave*. North Pomfret: Trafalgar Square Books.

FLETCHER, K. (2012). 'Durability, Fashion, Sustainability: The Processes and Practices of Use'. *Fashion Practice*. (4(2). pp 221-238.

FLETCHER, K. (2008). *Sustainable Fashion and Textiles: Design Journeys*. London: Earthscan.

FLETCHER, K. & GROSE, L. (2012). *Fashion & Sustainability: Design for Change*. London: Laurence King.

FRAYLING, C. (2011). *On Craftsmanship: Towards a New Bauhaus*. London: Oberon Masters.

FRAYLING, C. (1993). 'Research in Art and Design'. *Royal College of Art Research Papers*. 1(1). pp. 1-5. Available at: http://researchonline.rca.ac.uk/384/3/frayling_research_in_art_and_design_1993.pdf. Accessed: 12 December 2017.

GACA, A. (2016). 'Aleksandra Gaca, Collections'. *Aleksandra Gaca*. Available at: https://www.aleksandragaca.eu/collections. Accessed: 27 July 2018.

GERTSAKIS, J. & LEWIS, H. (2003). 'Sustainability and the Waste Management Hierarchy: A Discussion Paper on the Waste Management Hierarchy and Its Relationship to Sustainability'. Available at: http://scholar.googleusercontent.com/scholar?q=cache:bL3QfoXj6L8J:scholar.google.com/+Sustainability+and+the+Wast. Accessed: 03 January 2014.

GHURYE, S. (2014). 'Cutting Edge Trends in the Fashion Design Industry – Zero waste Fashion'. *Fuel4Fashion*. Available at: https://fuel4fashion.wordpress.com/tag/siddhartha-upadhyayas-dpol-direct-pattern-on-loom/. Accessed: 06 July 2017.

GLOBAL FASHION CONFERENCE. 2018. ' What's Going On? A Discourse on Fashion, Design and Sustainability Programme'. *Global Fashion Conference*. Available at: http://gfc-conference.eu/wp-content/uploads/2018/10/GF2018_PROGRAMME-FINAL.pdf. Available at: http://gfc-conference.eu/wp-content/uploads/2018/10/GF2018_PROGRAMME-FINAL.pdf. Accessed: 08 November 2018.

GOLDSWORTHY, K. (2012). 'Laser Finishing: A New Process for Designing Recyclability in Synthetic Textiles'. (PhD Thesis). London: University of the Arts London.

GOLDSWORTHY, K. & TELFER, D. (2012). 'Seamsdress'. *Textile Toolbox*. Available at: http://www.textiletoolbox.com/media/uploads/project-downloads/seamsdress.pdf. Accessed: 09 November 2018.

GRADY, E. (2008). 'High Tech Meets Low Waste in New Computer Generated Eco Fashion'. *Treehugger*. Available at: https://www.treehugger.com/style/high-tech-meets-low-waste-in-new-computer-generated-eco-fashion.html. Accessed: 06 July 2017.

GRAY, C. & MALINS, J. (1995). 'Appropriate Methodologies for Artists, Designers & Craftspersons: Research as a Learning Process'. *Carole Gray*. Available at: http://carolegray.net/Papers%20PDFs/cc.pdf. Accessed: 12 April 2014.

GREENPEACE. (2016). 'Timeout for Fast Fashion'. *Greenpeace: Hamburg*. Available at: http://www.greenpeace.org/international/Global/international/briefings/toxics/2016/Fact-Sheet-Timeout-for-fast-fashion.pdf. Accessed: 06 July 2017.

GREENHALGH, P. (1990). 'Introduction to Modernism in Design' in: LEES-MAFFEI, G. & HOUZE, R. (2010). The Design History Reader. Oxford: Berg. pp. 91-97.

GROTH, C. (2017). 'Making Sense Through the Hands: Design and Craft Practice Analysed as Embodied Cognition'. (PhD Thesis). Helsinki: Aalto University School of Arts, Design and Architecture.

GUGGENHEIM. (c.2018). 'Form Follows Function'. *Guggenheim*. Available at: https://www.guggenheim.org/arts-curriculum/topic/form-follows-function. Accessed: 10 October 2018

GWILT, A. (2011). 'Make - Producing Sustainable Fashion'. In: GWILT, A. & RISSANEN, T. (Eds.). (2011). S*haping Sustainable Textiles Changing the Way we Make and Use Clothes*. London: Earthscan. pp.59-73.

HARRIS, J. (2013). 'Digital Skin: How Developments in Digital Imaging Techniques and Culture Are Informing the Design of Futuristic Surface and Fabrication Concepts'. *Textile: The Journal of Cloth and Culture*. 11(3). pp. 242–261.

HARRIS, J. (2012). 'Digital Practice in Material Hands: How Craft and Computing Practices Are Advancing Digital Aesthetic and Conceptual Methods'. *Craft Research*. 3(1). pp. 91–112.

HASEMAN, B. & MAFE, D (2009) 'Acquiring Know-How: Research Training for Practice-Led Researchers'. In: SMITH, H. & DEAN, R, T. (Eds.) *Practice-Led Research, Research-Led Practice in the Creative Arts. Research Methods for the Arts and Humanities.* Edinburgh: Edinburgh University Press. pp. 153–165.

HEMMINGS, J. (2012). *Warp and Weft: Woven Textiles in Fashion, Art and Interiors.* London: A & C Black Publishers Ltd.

HILES, D. (2001). 'Heuristic Inquiry and Transpersonal Research'. *The Virtual Office of Dave Hiles*. Available at: http://www.psy.dmu.ac.uk/drhiles/HIpaper.html. Accessed: 26 May 2018.

HOSSEINI, R, S, A. & VALIZADEH, M. (2011) 'Properties of Fibers and Fabrics That Contribute to Human Comfort' in SONG, G. (Ed.). *Improving Comfort in Clothing.* Cambridge: Woodhead Publishing. pp.62–78.

HOWARTH, D. (2016). 'Issey Miyake Bakes Fabric to Pleat Spring Summer 2016 Garments'. *Dezeen*. Available at: Link: http://www.dezeen.com/2016/01/08/spring-summer-2016-fashion-collection-issey-miyake/. Accessed: 20 June 2016.

HOWARTH, D. (2014). 'Issey Miyake's focus is "being innovative with technology" says head of womenswear'. *Dezeen*. Available at: http://www.dezeen.com/2014/11/12/issey-miyakeyoshiyuki-miyamae-interview-3d-stretch-seam-fashion-technology/. Accessed: 20 June 2016.

IDEAS ON DESIGN. (2013). 'Creative Masters: Reiko Sudo'. *Ideas On Design*. Available at: http://ideasondesign.net/speakers/speakers/reiko-sudo/. Accessed: 06 May 2017.

INDUSTRIAL FABRICS ASSOCIATION INTERNATIONAL. (2015). 'Progress in Separating, Recycling Cotton and Polyester Blends'. I*ndustrial Fabrics Association International*. Available at: https://www.ifai.com/2015/07/15/progress-in-separating-recycling-cotton-and-polyester-blends/. Accessed: 25 September 2017.

INGOLD, T. (2010). 'Transformations of the Line: Traces, Threads and Surfaces'. *Textile*. 8(1). pp.10–35.

IRWIN, T. (2015). 'Transition Design: A Proposal for a New Area of Design Practice, Study, and Research'. Design and Culture. 7(2). pp. 229-246.

IRWIN, T. KOSSOFF, G. & TONKINWISE, C. (2015). Transition Design Provocation. Design Philosophy Papers. 13(1). pp. 3-11.

IRWIN, T. TONKINWISE, C. &. KOSSOFF, G. (2015). 'Transition Design: An Educational Framework for Advancing the Study and Design of Sustainable Transitions'. *6th International Sustainability Transitions (IST) Conference*. Brighton: University of Sussex. Available at: https://s3.amazonaws.com/academia.edu.documents/38615542/Irwin_Tonkinwise_Kossof_IP.pdf?response-content-disposition=inline%3B%20filename%3DTransition_Design_An_Educational_Framewo.pdf&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Credential=AKIAIWOWYYGZ2Y53UL3A%2F20190813%2Fus-east-1%2Fs3%2Faws4_request&X-Amz-Date=20190813T200138Z&X-Amz-Expires=3 600&X-Amz-SignedHeaders=host&X-AmzSignature=a736fed05fece3705883c61a165e58ffbe877737 b6019084605ce7bcbd24f1b8. Accessed: 13 August 2019.

ISSEY MIYAKE. (2016). 'Issey Miyake: Autumn Winter 2016 Video'. *Issey Miyake Inc*. Available at: http://www.isseymiyake.com/en/ brands/issey_miyake.html. Accessed: 13 July 2016.

ISSEY MIYAKE. (c.2016). 'Making Things'. *Issey Miyake Inc*. Available at: https://www.isseymiyake.com/en/brands/isseymiyake/making. 05 January 2018.

JAMES, A, M. ROBERTS, B, M. & KUZNIA, A. (2016). 'Transforming the Sequential Process of Fashion production: Where zero-waste pattern cutting takes the lead in creative design'. *International Journal of Fashion Design, Technology and Education*. 9(2). pp. 142 -152. DOI: 10.1080/17543266.2016.1167253.

JAR. (2017). 'About: Journal for Artistic Research'. *Journal for Artistic Research*. Society for Artistic Research. Available at: http://jar-online.net/about-jar/. Accessed: 08 September 2018.

JAYARAMAN, S. & PARK, S. (2001). *Full-fashioned Garment with Sleeves Having Intelligence Capability* (Patent). Available at: http://www.google.com/patents/US6315009. Accessed: 07 January 2016.

JAYARAMAN, S. PARK, S. & RAJAMANICKAM, R. (2000). *Full-fashioned Weaving Process for Production of a Woven Garment with Intelligence Capability* (Patent). Available at: http://www.google.co.uk/ patents/US6145551. Accessed: 07 January 2016.

JIANG, K. (2009). 'Time and Temperature'. In: SANDU CULTURAL MEDIA CO LTD. (Ed.) (2009). *Fabric: Metallic Textile Design of Kinor Jiang*. Hong Kong: Sandu Publishing Co Ltd. pp. 25-47.

JOHNSON, I. & COHEN, A, C. (2010). *Pizzuto's Fabric Science*. (9th Edition). United States: Fairchild Books.

JOHNSTONE, L. (2015). *Digital Handmade: Craftsmanship and the New Industrial Revolution*. London: Thames and Hudson.

KANE, F. (2013). 'Publication Review: Digital Visions in Fashion + Textiles: Made in Code, Sarah E. Braddock Clarke and Jane Harris 2012'. *Craft Research*. 4(2). pp. 289–292.

KAUFMANN, J. (2012). 'An Introduction to 3-D Weaving'. T*extile World*. Jul/Aug 2012.

KAWAMURA, Y. (2004). 'The Japanese Revolution in Paris Fashion'. *Fashion Theory*. 8(2). pp. 195-224.

KAWLRA, A. (2002). 'The Kimono Body'. *Fashion Theory*. 6(3). pp. 299-310.

KLEINING, G. & WITT, H. (2000). 'The Qualitative Heuristic Approach: A Methodology for Discovery in Psychology and the Social Sciences. Rediscovering the Method of Introspection as an Example'. *Forum: Qualitative Social Research*. 1(1), Art. Available at: http://www.qualitative-research.net/index.php/fqs/article/view /1123/2495. Accessed: 26 May 2018.

KODA, H. & MARTIN, R. (2002). 'Orientalism: Visons of the East in Western Dress'. *Metropolitan Museum of Art*. Available at: http://www.metmuseum.org/toah/hd/orie/hd_orie.htm. Accessed: 13 March 2015.

KOPPLIN, J. (2002). 'An Illustrated History of Computers Part 2'. *Computer Science Lab*. Available at: http://www.computersciencelab.com/ComputerHistory/HistoryPt2.htm. Accessed: 29 September 2016.

KUUSK, K. (2016). 'Smart Textiles for Wellbeing'. Tekstiililehti. Available at: http://www.tekstiililehti.fi/fi/ajankohtaista/smart+textiles+for+ wellbeing+may+2016/. Accessed: 26 July 2018.

LAWSON, B. (2006). *How Designers Think: The Design Process Demystified*. (4th Edition). Oxford: Elsevier Architectural Press.

LEE, Y. (2016). 'Seaming, Writing, and Making Strange: between material and text'. *Studies in Material Thinking*. Vol. 14. Experience/Materiality/ Articulation'. Available at: https://materialthinking.org/papers/224. Accessed: 16 June 2016.

LEFFERTS, J. (2015). 'Gestalt Process'. *T:W:O by Jacqueline Lefferts*. Available at: http://www.jacquelinelefferts.com/#/gestaltprocess/. Accessed: 06 November 2018.

LEHMANN, A, S. (2012). 'Showing Making: On Visual Documentation and Creative Practice'. *The Journal of Modern Craft*. 5(1). pp.9–23.

LEHMANN, U. (2012). ‘Making As Knowing: Epistemology and Technique in Craft’. *The Journal of Modern Craft.* 5(2), pp.149–164.

LEINIKKA, M. HOUTILAINEN, M, SEITAMAA-HAKKARINEN, P. GROTH, C. RANKANEN, M. & MÄKELÄ, M. (2016). ‘Physiological Measurements of Drawing and Forming Activities’. In: *Proceedings of DRS2016: Design + Research + Society Future-Focused Thinking.* Vol.7 Embodied Making and Learning. pp. 2941-2958.

LINDQVIST, R. (2015). ‘Kinetic Garment Construction: Remarks on the Foundations of Pattern Cutting’. (PhD Thesis). Boras: The Swedish School of Textiles, University of Boras.

LINDQVIST, R. (2013) ‘On the Logic of Pattern Cutting: Foundational Cuts and Approximations of the Body’. (Licentiate Thesis) Boras: The Swedish School of Textiles, University of Boras. Available at: http://bada.hb.se/handle/2320/11957. Accessed: 09 January 2015.

MALAFOURIS, L. (2013). *How Things Shape the Mind: A Theory of Material Engagement.* Cambridge: MIT Press.

MALAFOURIS, L. (2005). ‘The Cognitive Basis of Material Engagement: Where Brain, Body and Culture Conflate’. in DeMarrais, E. Gosden, C. & Renfrew, C. (Eds.). *Rethinking Materiality: The Engagement of Mind with the Material World.* Cambridge: McDonald Institute for Archaeological Research. pp. 53–61.

MANONIK. (2017). ‘Manonik, Principles’. *Manonik.* Available at: http://www.manonik.com/about/. Accessed: 26 July 2018.

MARGETTS, M. (2018). ‘The Growing is the Thing’. *Crafts Magazine.* No. 274. Sept/Oct 2018. pp. 36-44.

MARTIN, R. (1995). ‘Our Kimono Mind: Reflections on Japanese Design: A Survey Since 1950’. *Journal of Design History.* 8(3). pp. 215-223.

MCCANN, J. & BRYSON, D (Eds.). 2009. *Smart Clothes and Wearable Technology.* Cambridge: Woodhead Publishing in Textiles.

MCCANN, J. MORKSKY HAMK, S. & DONG, X. (2009). ’Garment Construction: Cutting and Placing of Materials’. In: MCCANN, J. & BRYSON, D. (Eds.). (2009). *Smart Clothes and Wearable Technology.* Cambridge: Woodhead Publishing in Textiles. pp.235–261.

MCLAREN, A. (2015). ‘Angharad McLaren Textiles’. Angharad McLaren. Available at: http://www.angharadmclaren.co.uk/#/angharad-mclaren-textiles/. Accessed: 29 July 2018.

MCLAREN, A. GOWOREK, H. COOPER, T. OXBORROW, L. & HILL, H. (2016). 'The Effects of Consumer Attitudes on Design for Product Longevity: The Case of the Fashion Industry' in *Design Research Society 50th Anniversary Conference Proceedings*. pp.3831-3846. Brighton: University of Brighton. 27-30 June 2016.

MCCULLOUGH, M. (1997). 'Abstracting Craft: The Practiced Digital Hand'. In: ADAMSON, G. (Ed.) *The Craft Reader*. Oxford: Berg. pp. 310-316.

MCNIFF, J. (2013). *Action Research: Principles & Practice* (3rd Edition). London: Routledge.

MCNIFF, J. (2002). 'Action Research for Professional Development: Concise Advice for New Action Researchers (3rd Edition)'. *Jean McNiff*. Available at: http://www.jeanmcniff.com/ar-booklet.asp. Accessed: 12 April 2014.

MCNIFF, J. LOMAX, P. & WHITEHEAD, J. (2003). *You and Your Action Research Project* (2nd Edition). London: Routledge Falmer.

MCQUILLAN, H. (2017a). ' PhD: Hybrid Zero Waste Fashion Practice'. *Holly McQuillan*. Available at: https://hollymcquillan.com/portfolio/hybrid-zero-waste-practice/. Accessed: 27-Sep-2018.

MCQUILLAN, H. (2017b). '2017 GWNZ Fellowship: Mid-Term Report'. *Graduate Women New Zealand*. Available at: http://www.gwnz.org.nz/wp-content/uploads/2017/05/McQuillan-Holly-mid-term-report-17.pdf. Accessed: 27-Sep-2018.

MCQUILLAN, H. (2014). *Zero Waste Fashion and Textile Design Seminar.* London: UAL Chelsea College of Art. 28 March 2014.

MCQUILLAN, H. (2011). 'Make – Zero-waste Design Practice: Strategies and Risk Taking for Garment Design'.In: GWILT, A. & RISSANEN, T. (Eds.). (2011). S*haping Sustainable Textiles Changing the Way we Make and Use Clothes*. London: Earthscan. pp.83-97.

MCQUILLAN, H. (2010). 'Zero-Waste Pattern Cutting Process'. *Holly McQuillan.* Available at: http://hollymcquillan.com/download/. Accessed: 04 December 2013.

MCQUILLAN, H. & RISSANEN, T. (2011). 'Yield: Making Fashion Without Making Waste' (Exhibition Catalogue). *Yield*. Available at: http://yieldexhibition.com/. Accessed: 04 December 2013.

NG, M, C, F. & ZHOU, J. (2013). *Innovative Jacquard Textile Design Using Digital Technologies*. Cambridge: Woodhead Publishing Limited. Excerpt available at: https://bit.ly/2LUgarw. Accessed: 28-May-2014.

NG, M, C, F. WANG, Z. HU, J. SZETO, Y, C. (2010). ‘Shapeable Stretch Textiles via Compound Weaves for Seamless Woven Fashion’. *Textile Research Journal*. 80(12) pp.1191–1200.

NG, M. C. F. HU, J. SZETO, Y, C. & WANG, Z. (2007). ‘Integrated Design of Seamless Fashion in Woven Textile with Multilayer’. *Research Journal of Textile and Apparel* .11(2). pp. 67–74.

NG, M. C. F. (1999). ‘A Study of Techniques Processes and Procedures Enabling Creation of Seamless Fashion Towards Innovative Ends’. *Research Journal of Textile and Apparel*. 3(2). pp41-52.

NIEDDERER, K. & IMANI, Y. (2008). ‘Developing a Framework for Managing Tacit Knowledge in Research Using Knowledge Management Models’. In: *Undisciplined! Design Research Society Conference*. Sheffield: Sheffield Hallam University. Available at: http://shura.shu.ac.uk/507/. Accessed: 01 August 2014.

NIEDDERER, K & TOWNSEND, K. (2014). ‘Designing Craft Research: Joining Emotion and Knowledge’. *Design Journal*. 17(3). pp.624–647.

NIINAMKI, K. (Ed). (2013). *Sustainable Fashion: New Approaches*. Helsinki: Aalto University. pp. 68-79. Available at: https://shop.aalto.fi/media/attachments/1ee80/SustainableFashion.pdf Accessed: 12 July 2018.

NIKE. (2016). ‘Top Things to Know About Sustainable Innovation at Nike’. *Nike Inc*. Available at: https://news.nike.com/news/sustainable-innovation. Accessed: 27 May 2018.

NIKE. (2014). ‘NIKE, Inc: The Most Technical First Layer in Sport. Nike Hyperwarm Flex’. *Nike Inc*. Available at: http://nikeinc.com/news/the-most-technical-first-layer-in-sport-nike-hyperwarm-flex#/inline/33747. Accessed: 15 October 2015.

NIMKULRAT, N. RAEBILD, U. & PIPER, A. (Eds.) (2018). ‘Soft Landing of Fashion and Textile Education’ Cumulus Think Tank Series. Helsinki: Aalto University, School of Arts, Design & Architecture.

NIMKULRAT, N. KANE, F. & WALTON, K. (Eds.) (2016). *Crafting Textile in the Digital Age*. London: Bloomsbury.

NIMKULRAT, N. (2012). ‘Hands-on Intellect: Integrating Craft Practice into Design Research’. *International Journal of Design*. 6 (3).

NIMKULRAT, N. (2010). ‘Material Inspiration: From practice-led research to craft art education’. *Craft Research*. Vol. 1. pp. 63-84.

NIINIMAKI, K. & ARMSTRONG, C. (2013). 'From Pleasure in Use to Preservation of Meaningful Memories: A Closer Look at the Sustainability of Clothing via Longevity and Attachment'. *International Journal of Fashion Design, Technology and Education*. 6(3). pp. 190-199. DOI: 10.1080/17543266.2013.825737.

NOTTINGHAM TRENT UNIVERSITY. (2015). 'Research Group Develops Gloves Which Relieve Pain for Raynaulds Sufferers'. *Nottingham Trent University*. Available at: https://www.ntu.ac.uk/about-us/news/news-articles/2015/01/research-group-develops-gloves-which-relieve-pain-for-raynauds-sufferers. Accessed: 27 July 2018.

NUNO. (c.2018). 'Kibiso Story'. *Nuno Online*. Available at: https://www.nunoonline.com/pages/about-kibiso. Accessed: 29 July 2018.

O'CONNOR, K. (2010). 'How Smart Is Smart? T-Shirts, Wellness, and the Way People Feel about "Medical" Textiles'. *Textile: The Journal of Cloth and Culture*. 8(1). pp. 50–67.

O'CONNOR, E. (2007). 'Embodied Knowledge in Glassblowing: The Experience of Meaning and the Struggle Towards Proficiency'. *The Sociological Review*. 55(S1). pp.126–141.

O'MAHONY, M. (2011). *Advanced Textiles for Health and Wellbeing*. London: Thames & Hudson.

O'MAHONY, M. & BRADDOCK, S, E. (2002). *SportsTech: Revolutionary Fabrics, Fashion and Design*. London: Thames & Hudson.

OSBORNE, E, F. (2009). *Weaving Process for Production of a Full Fashioned Woven Stretch Garment with Load Carriage Capability* (Patent). Available at: https://bit.ly/2mKyXdI. Accessed: 07 January 2016.

OXBORROW, L. & CLAXTON, S. (2016). 'Extending Clothing Lifetimes: An Exploration of Design and Supply Chain Challenges'. In: *Design Research Society 50th Anniversary Conference Proceedings*. pp. 3815-3830. Brighton: University of Brighton. 27-30 June 2016.

PAINE, H. (2016). 'Laser Shaping: A Method for Controlling the Elastic Behaviour of Stretch Fabrics for a Targeted and Graduated Compressive Effect on the Body'. (PhD Thesis). London: Royal College of Art.

PALLASMAA, J. (2009). *The Thinking Hand*. Chichester: John Wiley & Sons.

PARRY-WILLIAMS, T. (2015). 'Made-by-hand: [Re]valuing Traditional (Japanese) Textile Practices for Contemporary Design.' *Craft Research*. 6 (2). pp. 165-186.

PARRY-WILLIAMS, T. (2007). 'Craft: Industry Interface – A dialogue between hand, heart and machine (an Anglo-Japanese collaboration)'. In: Follett, G. & Valentine, L. (Ed.). *New Craft – Future Voices Conference Proceedings*. Dundee: Duncans of Jordanstone College of Art & Design. pp. 73-85.

PEDGLEY, O. (2007). 'Capturing and Analysing Own Design Activity'. *Design Studies*. 28(5). pp.463–483.

PHILPOTT, R. (2012). 'Crafting Innovation: The Intersection of Craft and Technology in the Production of Contemporary Textiles'. *Craft Research.* 3(1). pp. 53–74.

PHILPOTT, R. (2011). 'Structural Textiles: Adaptable Form and Surface in Three Dimensions'. (PhD Thesis). London: Royal College of Art.

PIPER, A. (2016). 'Code, Decode, Recode: Constructing, Deconstructing and Reconstructing Knowledge Through Making'. In: *Proceedings of DRS2016: Design + Research + Society Future-Focused Thinking*. Vol.7 Embodied Making and Learning. pp. 2889-2965. https://static1.squarespace.com/static/55ca3eafe4b05bb65abd54ff/t/57489ca504426269f1c93e60/1464376485529/415+Piper.pdf. Accessed: 10 November 2018.

PIPER, A. (2014). 'Crafting the Composite Garment: The Role of Hand Weaving in Digital Production/Creation'. *Transitions: Rethinking Textiles and Surfaces*. Huddersfield: University of Huddersfield. 26-27 November 2014.

PIPER, A. & TOWNSEND, K. (2015). 'Crafting the Composite Garment: The Role of Hand Weaving in Digital Creation'. *Journal of Textile Design Research and Practice*. 3(1-2). pp.3-26. Available at: https://www.tandfonline.com/doi/abs/10.1080/20511787.2015.1127037. Accessed: 10 November 2018.

POINTCARRE. (2018). 'Pro Weave'. *Pointcarre Textile Software*. Available at: https://www.pointcarre.com/proweave.html. Accessed: 22 November 2018.

POLANYI, M. (1966). *The Tacit Dimension*. (Reissue Edition). London: University of Chicago Press.

POLLOCK, N. (2012). Made in Japan 100 Products, London: Merrell

RISSANEN, T. & MCQUILLAN, H. (2016). *Zero Waste Fashion Design*. Lonndon: Bloomsbury.

PRESS, M. & COOPER, R. (2003). *The Design Experience: The Role of Design and Designers in the Twenty-First Century*. Aldershot: Ashgate.

PYE, D. (1968). *The Nature & Art of Workmanship.* Cambridge: Cambridge University Press.

RAND EBBESEN, S. (2015). 'Signe Rand Ebbessen, Woven Textile Designer'. S*igne Rand Ebbessen*. Available at: http://signerandebbesen.com/woven-textile-designer/. Accessed: 27 July 2018.

RATHNAYAKE, A. PIPER, A. & TOWNSEND, K. (2012). 'Woven Garment with Integrated LED Yarn Technology'. *Future Textiles Exhibition*. London: Palace of Westminster.

RAY, S, C. (2012). *Fundamentals and Advances in Knitting Technology*. Cambridge: Woodhead Publishing Limited.

REASON, P. & BRADBURY, H. (Eds.). (2001). *Handbook of Action Research (Concise Paperback Edition)*. London: SAGE.

REDMAN, J. (1976). *Frame-loom Weaving*. New York: Van Nostrand Reinhold Ltd.

RICHARDS, A. (2012). *Weaving Textiles That Shape Themselves*. Ramsbury: The Crowood Press Ltd.

RISSANEN, T. & MCQUILLAN, H. (2016). *Zero Waste Fashion Design*. London: Bloomsbury.

RISSANEN, T. (2013). 'Zero-Waste Fashion Design: A Study at the Intersection of Cloth, Fashion Design and Pattern Cutting'. (PhD Thesis). Sydney: University of Technology Sydney.

RISSANEN, T. (2011). ' Designing Endurance Fashion'. In: GWILT, A. & RISSANEN, T. (Eds.). (2011). *Shaping Sustainable Textiles: Changing the Way we Make and Use Clothes.* London: Earthscan. pp. 127-138.

ROBERTS, J. (2014). 'Zero Waste Questionnaire'. *Subtraction Cutting by Julian Roberts.* Available at: https://subtractioncutting.tumblr.com/post/86887883276/zero-waste-questionnaire. Accessed: 26 May 2018.

ROBERTS, J. (2013). 'Free Cutting'. *The Cutting Class*. Available: https://www.thecuttingclass.com/subtraction-pattern-cutting-with-julian-roberts/. Accessed: 08 November 2018.

ROSSO, B, D. (2014). 'Creativity and Constraints: Exploring the Role of Constraints in the Creative Processes of Research and Development Teams'. *Organization Studies*. 35(4). pp. 551-585.

RUDGE, G. (2001). 'A Piece of Cloth'. *Crafts*. Nov/Dec 2001. 22–25.

SAIFEE, F. (2009). 'The Influence of Knitwear on Smart Wearables'. In: MCCANN, J. & BRYSON, D. (Eds.). (2009). *Smart Clothes and Wearable Technology*. Cambridge: Woodhead Publishing in Textiles. pp.111–130.

SALAZAR, L. (Ed.). (2008). *Fashion V Sport*. London: V&A Publishing.

SANTONI. (c.2014). 'Santoni Seamless'. *Santoni*. Available at: http://www.santoni.cn/en/seamless. Accessed: 16 October 2014.

SCANLAN, J. (2015). 'Pathmakers: Women in Craft, Art and Design Mid-century and Today'. *The Journal of Modern Craft*. 8(2). pp.109-114.

SCALON, J. (2004). 'Seamless: Issey Miyake Saw the Future of Fashion'. *Wired*. Vol. 12. 4. P.162-167. Available at: http://www.wired.com/wired/archive/12.04/miyake_pr.html. Accessed: 11 November 2013.

SCHILLIG, G. (2015). 'On Skins, Membranes and Folds: Textile spaces – spaces of communication'. *Craft Research*. 6(2). pp. 297-205.

SCHÖN, D, A. (1991). *The Reflective Practitioner: How Professionals Think in Action*. London: Ashgate.

SHAPE 3. (c.2007). 'Shape Weaving: Weaving of 3D Shells and 3D Tubes'. *Shape 3 Innovative Textiltechnik GmbH*. Available at: http://www.shape3.com/Frameset_Shape3.htm. Accessed: 20 November 2013.

SHIMA SEIKI. (2015).'WHOLEGARMENT'. *Shima Seiki*. Available at: http://www.shimaseiki.com/wholegarment/. Accessed: 03-Feb-2016.

SHISHOO, R. (Ed.). (2005).*Textiles in Sport*. Cambridge: Woodhead Publishing in Textiles.

SINGH SAWHNEY, A, P. (1972). 'Apparel Weaving – A New Concept'. *Textile Industries*. Dec 1972. pp.50-56.

SMITH, T. (2014). *Bauhaus Weaving Theory: From Feminine Craft to Mode of Design*. London. University of Minnesota Press.

SPENCER, D, J. (2001). *Knitting Technology*. (3rd Edition). Oxford: Pergamon.

SONG, G. Ed. 2011. I*mproving Comfort in Clothing*. Oxford: Woodhead Publishing Limited.

STERN, R. (2004). *Against Fashion: Clothing as Art, 1850-1930*. Cambridge: The MIT Press.

STURKEN, M. & CARTWRIGHT, L. (2001). *Practices of Looking: An Introduction to Visual Culture*. London: Oxford University Press.

STYLES, J. (1998). 'Dress in History: Reflections on a Contested Terrain'. *Fashion Theory*. 4(2). pp. 383-390.

SWANN, C. (2002). 'Action Research and the Practice of Design'. *Design Issues*. 18(2). pp. 49-61.

TAYLOR, J. (2015). 'The Technical Designer: A New Craft Approach for Creating Seamless Knitwear'. (PhD Thesis). Nottingham: Nottingham Trent University.

TAYLOR M, A. (1997). *Technology of Textile Properties*. (3rd Edition). London: Forbes Publications

TAYLOR, J. & TOWNSEND, K. (2014). 'Reprogramming the Hand: Bridging the Craft Skills Gap in 3D/digital Fashion Knitwear Design'. *Craft Research*. 5(2). pp.155–174.

TED. (c.2016). 'The TEN'. *Textile Environment Design*. Available at: http://www.tedresearch.net/teds-ten/. Accessed: 26 September 2017.

TEN BHÖMER. (2016). 'Vigour'. *Martijin ten Bhömer.* Available at: https://www.mtbhomer.com/portfolio/vigour/. Accessed: 26 July 2018.

TEXTRONICS. (2016). 'Textronics Energy-activated Fabrics'. *Textronics Inc*. Available at: http://www.textronicsinc.com/. Accessed: 17 August 2016.

TEXTILES INTELLIGENCE. (2018). 'Seamless Knitting and Stitch-free Seaming in Performance Apparel'. *Innovation in Textiles.* Available at: https://www.innovationintextiles.com/seamless-knitting-and-stitchfree-seaming-in-performance-apparel/. Accessed: 26 July 2018

THOMAS, L. (2009). 'Woven Structures and Their Impact in the Function and Performance of Smart Clothing'. In: MCCANN, J. & BRYSON, D. (Eds.). (2009) S*mart Clothes and Wearable Technology*. Cambridge: Woodhead Publishing in Textiles. pp.131–155.

TORTORA, P, G. (2015). *Dress, Fashion and Technology: From Prehistory to the Present*. London: Bloomsbury.

TOWNSEND, K. (2016). 'Closely Held Secrets: Embodied Knowledge in Digitally Crafted Textiles'. In: NIMKULRAT, N. KANE, F. & WALTON, K. (Eds.). (2016). *Crafting Textile in the Digital Age*. London: Bloomsbury. pp. 189-206.

TOWNSEND, K. (2004a). 'Transforming Shape: A Simultaneous Approach to the Body, Cloth and Print for Textile and Garment Design (synthesising CAD with Manual Methods)'. (PhD Thesis). Nottingham: Nottingham Trent University.

TOWNSEND, K. (2004b). 'Transforming Shape: Hybrid Practice as Group Activity'. *The Design Journal*. 7(2). pp. 18-31.

TOWNSEND, K. & GOULDING, R. (2011). 'The Interaction of Two and Three Dimensional Design in Textiles and Fashion'. In BRIGGS-GOODE, A. & TOWNSEND, K. (Eds.). (2011). *Textile Design: Principles, Advances and Applications*. Oxford: Woodhead Publishing. pp.288-322.

TOWNSEND, K. & MILLS, F. (2013). 'Mastering Zero: How the Pursuit of Less Waste Leads to More Creative Pattern Cutting'. *International Journal of Fashion Design, Technology and Education*. 6(2). pp. 104–111.

TOWNSEND, K. & SADKOWSKA, A. (2018). 'Textiles as Material Gestalt: Cloth as a Catalyst in the Co-designing Process'. *Journal of Textile Design and Research Practice*. 5(2). pp. 208-231.

TRULLEN, J. & TORBERT, B. (2013). 'First-, Second-, and Third-Person Research in Practice'. *The Systems Thinker.* Available at: https://thesystemsthinker.com/first-second-and-third-person-research-in-practice/. Accessed: 26 May 2018.

TWIGGER HOLROYD, A. (c.2017). 'Keep and Share'. *Amy Twigger Holroyd*. Available at: https://amytwiggerholroyd.com/Keep-Share. Accessed: 12 July 2018.

UAL. (c.2016). 'Textile Environment Design'. *The University of the Arts London*. Available at: http://www.arts.ac.uk/research/researching-at-ual/research-infrastructure/research-groups-networks-and-collaborations/textiles-environment-design/. Accessed: 26 September 2017.

UKEY, P, P. KADOLE, V & BORIKAR, S. (2013). '"Direct Pattern on Loom" – An Innovative Method of Garment Construction'. *Textile Science & Engineering*. 3(2). p. 131.

VALENTINE, S. (2011). 'Craft as a Form of Mindful Inquiry'. T*he Design Journal*. 14(3). pp. 283–306.

VAN DONGEN, P. (2016). 'Vigour'. *Pauline van Dongen*. Available at: http://www.paulinevandongen.nl/project/vigour/. Accessed: 26 July 2018.

VAN REES, H. (2014). 'Tweedlapse'. *Vimeo*. Available at: https://vimeo.com/98527123?from=outro-embed. Accessed: 16 June 2016.

VITRA DESIGN MUSEUM. (2001). *A-POC Making: Issey Miyake and Dai Fujiwara* (Exhibition Catalogue). Berlin: Vitra Design Museum.

WALMSLEY-JOHNSON, H. (2014). 'Sports Luxe: Does It Work for Older Women?'. *The Guardian*. Available at: http://www.theguardian.com/fashion/2014/oct/29/sports-luxe-does-it-work-for-older-women. Accessed: 15 May 2015.

WANG, X. (2011). 'A Study on Silk Full-Fashioned Weaving for Women's Wear'. *Advanced Materials Research* .175. pp.1035–1039.

WANG, X. NG, M, C, F. HU, J. & SZETO, Y, C.. (2009). 'Shapeable Stretch Textiles via Simple Weaves for Seamless Woven Fashion'. *Textile Research Journal*. 79(18). pp.1715–1724.

WATKINS, S, M. & DUNNE, L, E. (2015). *Functional Clothing Design: From Sportswear to Spacesuits*. London: Bloomsbury.

WATKINS, P. (2011). 'Garment Pattern Design and Comfort'. In: SONG, G. (Ed.). (2011). *Improving Comfort in Clothin*g. Cambridge: Woodhead Publishing. pp. 278–302.

WILSON, E. (2003). *Adorned in Dreams: Fashion and Modernity.* London: IB Tauris & Co Ltd.
WILSON, J. (2010). *Classic and Modern Fabrics: The Complete Illustrated Source Book*. London: Thames & Hudson.
WILSON, J. (2001). *Handbook of Textile Design: Principles, Processes and Practice*. Cambridge: Woodhead Publishing Ltd.
WOOD, N. (2006). 'Transmitting Craft Knowledge: Designing Interactive Media to Support Tacit Skills Learning'. (PhD Thesis) Sheffield: Sheffield Hallam University.
WRAP. (2017). 'Sustainable Clothing: A Practical Guide to Enhancing Clothing Durability and Quality'. *WRAP.* Available at: http://www.wrap.org.uk/sites/ les/wrap/ Sustainable%20Clothing%20G uide%202017.pdf. Accessed: 20 September 2017.
ZHENG, T. LI, S. JING, S. & OU, Y. (2012). 'Designing of 3D Woven Integrated T-Joint Tube'. *Textile Research Journal*. 83(11). pp.1143-1155.