Crafting the Composite Garment:

The role of hand weaving in digital creation

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There is a growing body of practice-led textile research, focused on how digital technologies can inform new design and production strategies that challenge and extend the field. To date, this research has emphasized a traditional linear transition between hand and digital production; with hand production preceding digital as a means of acquiring the material and process knowledge required to negotiate technologies and conceptualize designs. This paper focuses on current Doctoral research into the design and prototyping of 3D woven or 'composite' garments and how the re-learning, or reinterpreting, of hand weaving techniques in a digital Jacquard format relies heavily on experiential knowledge of craft weaving skills. Drawing parallels between hand weaving and computer programming, that extend beyond their shared binary (pixel-based) language, the paper discusses how the machine-mediated experience of hand weaving can prime the weaver to 'think digitally' and make the transition to digital production. In a process where the weaver acts simultaneously as designer, constructor and programmer, the research explores the inspiring, but often indefinable space between craft and digital technology by challenging the notion that 'the relationship between hand, eye and material' naturally precedes the use of computing (Harris 2012: 93). This is achieved through the development of an iterative working methodology that encompasses a cycle of transitional development, where hand weaving and digital processes take place in tandem, and techniques and skills are reinterpreted to exploit the advantages and constraints of each construction method. It is argued that the approach challenges the codes and conventions of computer programming, weaving and fashion design to offer a more sustainable clothing solution.

Keywords: composite garment, digital production, embodied knowledge, hand weaving, Jacquard weaving, zero-waste, 3D woven textiles

1. Introduction

This paper focuses on current Doctoral research, being undertaken by Anna Piper at Nottingham Trent University, into the development of the Composite Garment Weaving system (CGW); a method of garment production to construct and integrally shape seamless garments on the loom. Building upon Miyake's A-POC concept and using Piper's tacit knowledge of producing flat-packed garments, the research explores the garment shaping capabilities of craft weaving techniques by developing 3D woven garment prototypes. By constructing textile and garment simultaneously (Townsend 2004) the process minimizes material consumption and cutting waste, offering a more sustainable fashion solution than traditional approaches.

Piper's practice is informed by a background in hand weaving[1], incorporating a thorough understanding of materials and established technical knowledge of craft weaving techniques, derived through haptic engagement with different yarns and processes. Her research explores the inspiring, but often indefinable space between craft and digital technology, by challenging the notion that 'the relationship between hand, eye and material' naturally precedes the use of computing (Harris 2012: 93). This is achieved through the development of an iterative working methodology that encompasses a cycle of transitional development, where hand weaving and digital processes take place in tandem, and techniques and skills are reinterpreted to exploit the advantages and constraints of each construction method.

Contextualizing CGW, the paper reviews developments in fully-fashioned seamless garment production, existing approaches to minimizing production waste, and innovative 3D craft weaving techniques. It subsequently analyzes the role of embodied knowledge in hand and digital practice, exploring the notion that the weaver is primed to 'think digitally' by the experience of hand weaving. Employing the heuristic approach advocated by Lehmann (2012), and building upon the experimental philosophy of the Bauhaus weavers (Smith 2014), the 'Parallel Thinking and Making' methodology then advocates the integration of hand and digital processes as a platform for innovation. Finally, the outcomes of the technical phase of the research are described in conjunction with Piper's design influences; further informed by the Bauhaus weavers and the work of Issey Miyake, the role of the body and the mode of production are centrally positioned in the development of fabric and garment prototypes.

By developing an intuitive craft-based, design-led methodology that unites knowledge of hand weaving with CAD/CAM systems, the research aims to establish new 'creative partnerships with digital technology' (Kane 2013: 290). The integrated digital craft methodology challenges established linear design and production systems (Gwilt & Rissanen 2011) by recognizing the vital role of hand weaving in developing innovative techniques and textiles.

Drawing parallels between the mediated experience of hand weaving and the 'digital thinking' required in software[2] programming, the approach demonstrates that whilst computerized Jacquard weaving presents greater technical and manufacturing potential for woven textile designers, the role and value of hand weaving (experiential knowledge of craft techniques) is not diminished. Instead, the craft and digital realms work reciprocally and beneficially, with established skills in one acting as a catalyst for pushing the boundaries of the other.

2. Background

2.1. Fully-fashioned garment weaving

The project responds to the limited research undertaken into fully-fashioned garment weaving, in comparison with the growth in research into integrally shaped seamless fashion knitwear (see for example Taylor & Townsend 2014). To date, research into 3D weaving has generally concentrated on architectural, engineering and medical applications (see Zheng et al. 2012; Behere & Mishra 2008).

Weaving presents significant challenges for fashioning and shaping textiles compared to knitting,[3] due to the predetermined unchanging width of the warp, and the use of two yarn sets (warp and weft). These constraints, combined with the complexity of integrating the design of 2D textiles with 3D garments, have restricted design-led research into fully-fashioned garment weaving. Although there has been some research into seamless weaving for the construction of functional garments integrating intelligent technology (Rathnayake, Piper & Townsend 2012; Osborne 2010; Jayaraman et al. 2000) in the small number of studies where fashion applications have been considered they have concentrated on "shapeable stretch textiles" (Ng et al. 2010; Wang et al. 2009) using digital Jacquard weaving techniques to produce a limited garment range. To date, Issey Miyake's A-POC, developed with Dai Fujiwara is the most high profile fully-fashioned woven garment, incorporating the strongest emphasis on design aesthetics. Discussing A-POC in 2001, Miyake said:

> 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 customization by enabling customers to cut a variety of simple garment shapes and accessories from a length woven from single and double-cloth structures. His 1 3 2 5. ISSEY MIYAKE (2010) collection developed by Reality Lab, explored resource consciousness through origami-style wearable sculptures that transformed between two and three dimensions (Miyake Design Studio 2015: Online). Miyake has always focused on the creative possibilities of technology. Over the past three years, his director of womenswear Yoshiyuki Miyamae has developed a new 3D Steam Stretch 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).

Other innovative, shaped woven fabrics have been produced in the craft realm by Ann Richards 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). These experimental 2D/3D textiles demonstrate the potential for a different approach to garment shaping and fitting that does not rely solely on stretch.

Building on these examples, Piper works with standard (un-adapted) hand and digital Jacquard looms[4] to produce garments that are constructed on and wearable direct from the loom. The process moves away from the conventional weaving of at rectangular pieces or lengths of fabric (to be cut into garment shapes and constructed later), by weaving seamless, shaped garments as integral composite forms that will transform into 3D once cut from the loom. Figure 1 shows a hand woven geometric jacket and dress, and Figure 2 a Jacquard

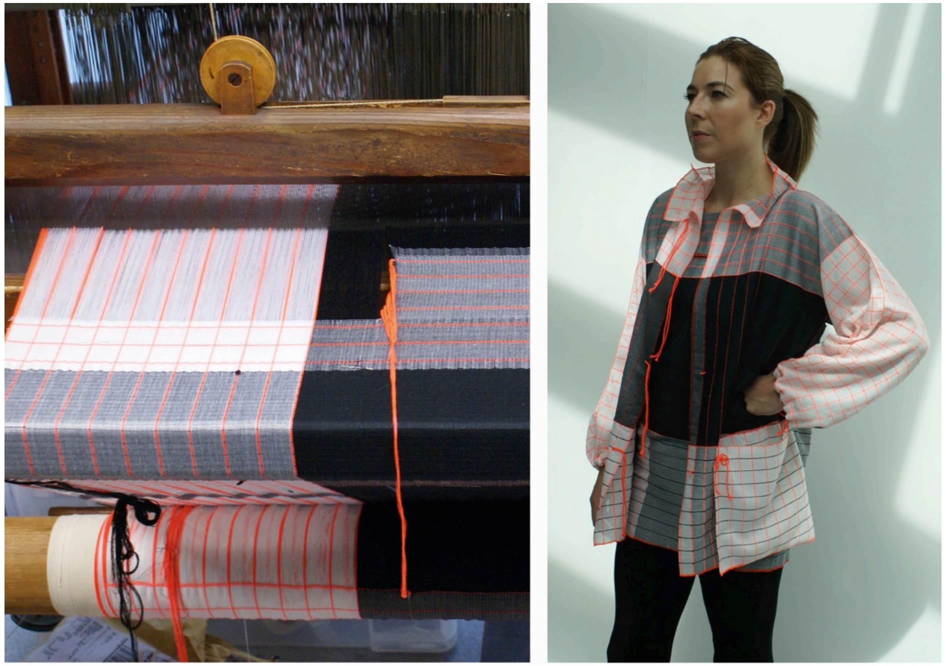

Figure 1 Anna Piper (2013) Dress Under Construction and Hand Woven Dress and Jacket.

Figure 2 Anna Piper (2013) Jacquard Woven Bodice Prototype Detail

woven bodice prototype with curved shaping. These tubular constructions are produced using single and double cloth weaving techniques; eliminating sewing and minimizing cutting waste by producing the textile and garment simultaneously - offering a more sustainable fashion solution than traditional approaches.

2.2. Minimizing Waste

Piper's 'composite garment weaving system' incorporates the principles of sustainable design by removing cutting waste, which averages 15–20% of the fabric used in traditional garment production (Rissanen 2013). A number of 'sustainable interventions' have been identified to reduce the waste resulting from traditional design and production models (Gwilt & Rissanen 2011). According to McQuillan, zero-waste design practice requires design strategies that incorporate risk taking (See 2.4 in Gwilt & Rissanen 2011: 83). Many of those listed incorporate creative pattern cutting such as the Jigsaw approach developed by Timo Rissanen (informed by Julian Robert's Subtraction Cutting method) and have influenced Piper's design strategy and philosophy (McQuillan in Gwilt & Rissanen 2011: 93). The Jigsaw approach whereby all the available fabric is used, is reinforced by Piper at the start of the design process by deciding on the width of the warp/fabric and the particular garment to be simultaneously woven/designed. Rissanen works in a similar way, based on his observations of Roberts, Yeoh Lee Teng and Yoshiki Hishinuma's practice, who use the garment pattern as the originator of their fashion designs (Ibid: 92).

Other creative approaches that minimize waste have been developed for fashion knitwear; fully-fashioned and seamless garments that only the fabric required to construct a garment eliminate cutting waste (Taylor and Townsend 2014: 165). Piper's CGW system draws on these approaches by integrating shaping via fully-fashioned garment weaving, while minimizing material production and consumption. The concept also builds on the researcher's experience of producing flat-packed garments[5] that have no integral 3D shaping, but are geometric envelopes, given form through the shape and support of the body.

2.3. 'Knowing' Through Making

Two types of knowledge converge in skillful practice; technical taught principles (explicit knowledge) of a craft discipline are combined with knowledge derived through engagement with materials and process, known as embodied (or experiential) knowledge (Lehmann 2012; Polanyi 1966). Dreyfus and Dreyfus (1988) state that in the progression from novice to expert maker, rules are made meaningful through experience, and experience and knowledge evolve into intuitive action and practiced understanding. The acquisition of skill and skillful 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.

'Making' frequently involves the use of a tool(s) to facilitate or assist in the manipulation and shaping of materials. Using the tool, the maker is able to experience the material and form the object, transferring and externalizing ideas from mind, via the body and tool, to the material world (Malafouris 2013). Skillful 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.

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 curtail sensory (material) feedback. It is

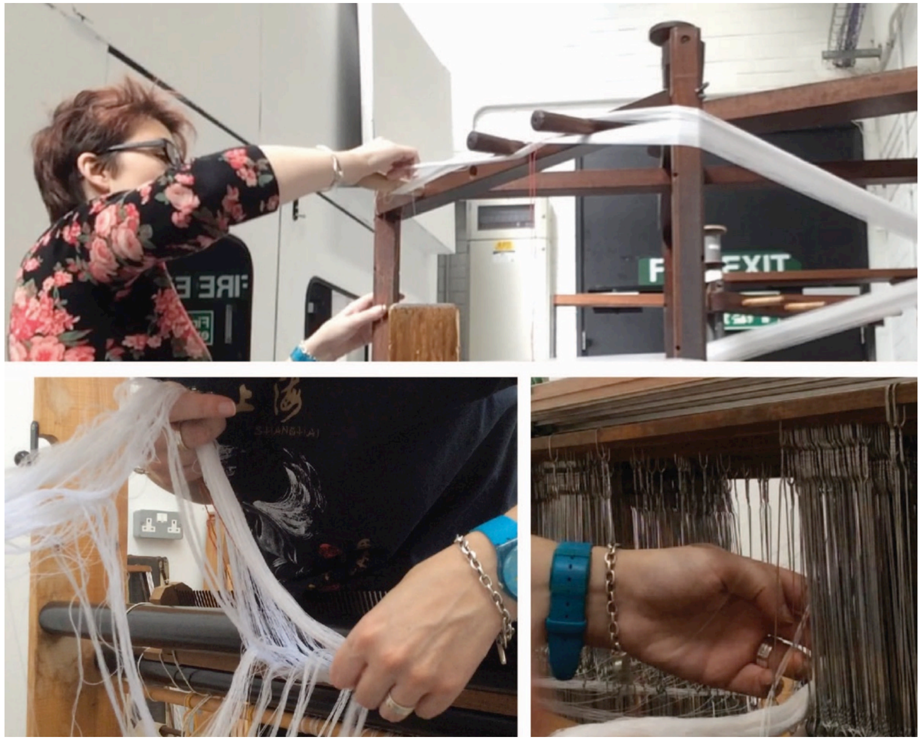

Figure 3 Anna Piper (2014) Preparatory Processes – Warping, Winding-on and Threading

during the preparation of the loom, in the process of warping, winding and threading, seen in Figure 3, that significant and prolonged engagement with materials in their uninhibited state occurs. 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. (Smith 2014: 64)

In the dressing of the loom a conscious and intuitive 'reading', internalizing and analyzing 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. Selections are therefore based on knowledge of the relationship between their "materiality and [potential] expressivity" (Ibid: 65).

In her 1946 essay 'Constructing Textiles' Anni Albers states, "A design on paper, however, cannot take into account the ne surprises of a material and make imaginative use of them." (1961: 13). In 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 co-exist (Niedderer & Imani 2008) forming "productive relationships between theory and practice" (Lehmann 2012: 150).

2.4. Digital and material thinking: parallel practices

Hand weaving, being a machine-mediated activity, prepares the weaver for the “disembodied” (Philpott 2012) experience of digital production. 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). McCullough describes a process in which a system is ‘read’ in multiple ways, the user learns to adapt, identifying patterns and recognizing sequences, and the hand begins to work in “complementary modes” (Ibid). However, this activity is informed and sustained by the knowledge and craft skills accrued during hand making.

Similarly, Piper identifies parallels between weaving (particularly in the construction of 3D fabrics/garments) and computer use, that extend beyond the technology being employed as a tool that can be mastered like any other. Weaving and computer programming share a binary language.[6] 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. 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 as the weaver moves from the hand loom to digital software.

In the construction of 3D woven prototypes, 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, flattened into a 2D format that is bound by the rules of geometry and limitations of the machine 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, conceptualized and translated via the codes and conventions of the mode of production.

Harris (2013) discusses the building of ‘digital skins’ and textiles using CGI software, describing the physical characteristics of material surfaces as having:

> an infinite array of characteristics that are generally taken for granted in real world scenarios and all of

> which acquire a new level of complexity when translated into what are effectively mathematical prose for digital application. (Ibid: 245)

These characteristics include color, texture, light, reflection and shadow. This is emphasized by Harris's reference to the construction of physical garments for use by CG programmers in the making of the film 'Avatar' (Ibid: 246), suggesting that material knowledge and understanding is required for a successful 'realistic' outcome. This supports Piper's methodological approach, where tacit knowledge of physical weaving is integral to the process of 'retaining control' of her creativity within the digital production process (Taylor and Townsend 2014: 159). The removal of conventional fashion design shaping and construction techniques (such as darting and cutting) and the simultaneous construction of textile and garment, requires complex problem solving skills to produce a successful outcome. Whether manufacturing using hand or digital methods, the individual characteristics of each component are intrinsic to the success of the original design. Weave structure, yarn properties, fabric density and the influence they have on each other all have to be understood and carefully balanced in order to shape the textile.

3. Methodology

3.1. Parallel thinking and making

Piper's research operates within a framework of creative experimental first-person action research, with outcomes evolving through experimentation and reflection. Situating the maker at the centre of creative practice, hand and digital production take place in tandem. The methodology (illustrated in Figure 4) draws upon heuristic thinking and Lawson's "parallel lines of though" (Lawson 2006), as well as from Bauhaus Weaving Theory, which places hand experimentation at the heart of innovative practice "to exploit the limits of the craft...in order to yield better products for industry." (Smith 2014: 47).

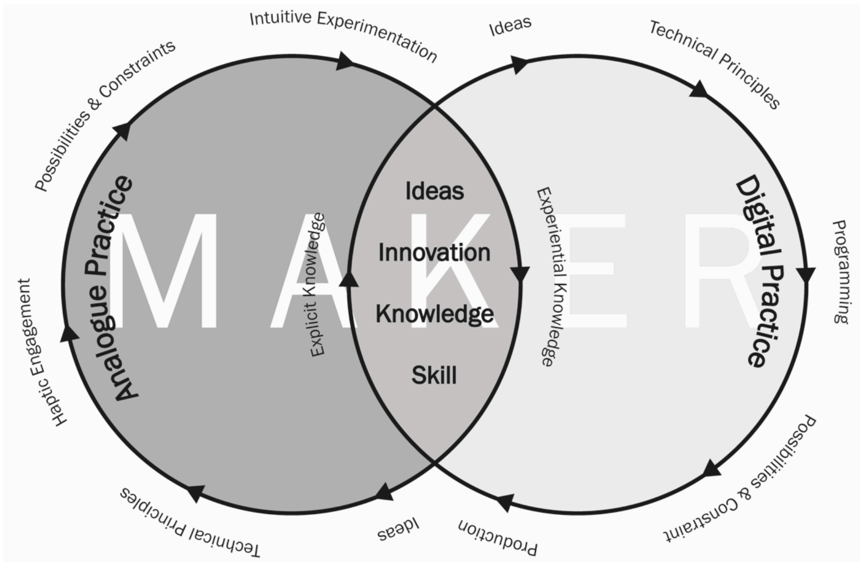

Figure 4 Anna Piper (2014) Design Methodology Diagram Integrating Hand and Digital Practice

> 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, cited in Smith 2014: 64)

The Bauhaus weavers emphasized the importance of material and process engagement in exploiting the technical possibilities of mechanized production, establishing its parameters and improving the relationship between “human subjects and woven things.” (Smith 2014: 48). While Albers and her contemporaries did much to elevate the craft and status of hand weaving, it is partly because of this that it remains at the forefront of a linear process of design development and production, which limits the possibilities of innovation through intervention and a reciprocal exchange of knowledge.

3.2. 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), advocating “reconsidering the structure of working processes” (Ibid: 153) as a platform for innovation and conceptual thinking. To challenge existing thinking and generate new knowledge demands a departure from prescribed rules and established tradition; this 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 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 organizational rather than a linear supply chain model, with the designer at the core of an integrated process to allow them to “design, plan and create a new garment design in tandem with the integration of sustainable strategies.” (Gwilt & Rissanen 2011).

3.3. Parallel Processes for Design and Production

In 3D composite garment weaving multiple textile and fashion processes take place in parallel; requiring a combination of

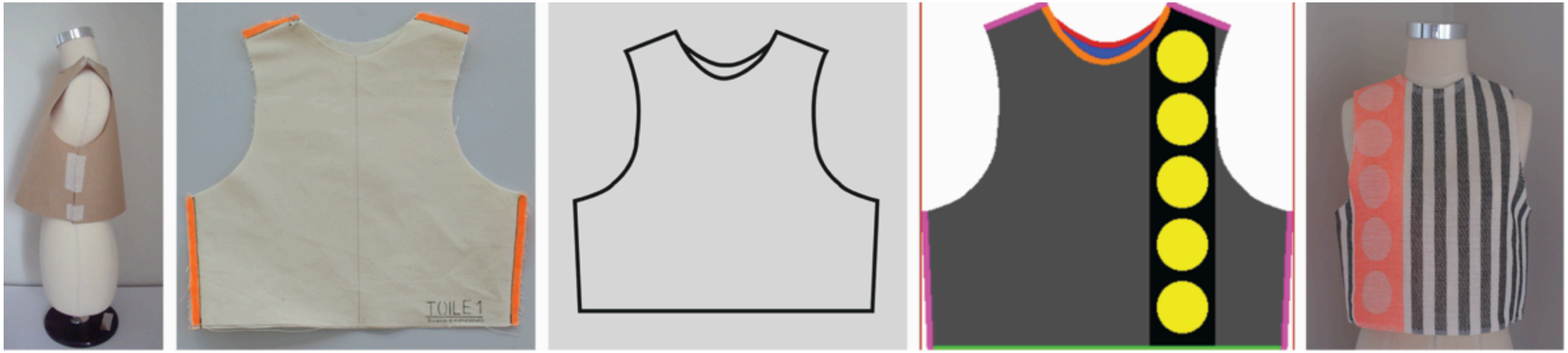

Figure 5 Anna Piper (2013) Production Phase for Digital Jacquard Garment.

experimentation, open-mindedness and embodied knowledge, to understand the potential of materials, processes and modes of production, and to exploit the opportunities of simultaneous textile and garment 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; modeling on the garment stand, toiling, the construction of a 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. It is this multifaceted approach that results in a 'composite' garment, encompassing all these 2D and 3D design elements.

As there is no opportunity to partially construct, to (try on) or adjust the composite prototype during production, initial toiling plays a crucial role in the garment's success. The toile is a template for the final dimensions of the woven garment. In hand weaving the warp (its design and threading) is developed from this pattern in conjunction with the chosen fabric design and selected yarns. The digital garment production process (Figure 5) incorporates the conversion of the physical toile to a digital image, providing the base data for programming to which weave structures are applied - a process that unites conventional analogue fashion (pattern making) techniques with digital programming for woven construction.

Piper combines a rigorous approach to the technical analysis of each design component and process (systematically evaluating and comparing construction quality, functionality and design aesthetics), with comprehensive reflective practice (see Table 1 for methods). “Reflection in Action” (Schon 1991) intuitively occurs during making as decisions are made, problems-solved and ideas evolve in response to engagement with the process drawing (consciously and unconsciously) from technical principles and experiential knowledge.

The heuristic approach to design (Abbott 2004), borrows, adapts and combines methods from paper folding, zero-waste (ZWPC) pattern cutting and whole garment knitting to stimulate new ways of working and thinking about design, construction and the integration of sustainable practice. Combined with traditional weaving processes, this experimental strategy has resulted in the development of techniques that capitalize on inherent characteristics of woven construction and its perceived limitations.

Reflective Method	**Purpose**
Blog and paper-based journal	• To document and reflection on action, to examine and advance practice • To enable questioning, deconstruction and reconstruction of practice
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

Table 1 Reflective Methods

4. Composite Garment Development: The Interrelating of Garment Shape and Structure

4.1. The Influence of 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.

In Piper's research the body is central to garment design; its shape, anatomy and movement guide design (as demonstrated in the design visualization in Figure 6); with the body's relationship to the textile, the way it behaves on the body and responds to its biomechanical movements (Ibid: 95), directing construction. Garment designs intend to exploit the functional and creative potential of simultaneous and seamless construction, mapping the body "to combine several functions in a single smooth layer to respond to the specific needs of each body part." (Shishoo 2005: 26) through engineered and seamless paneling of different textile qualities to form and fit garments.

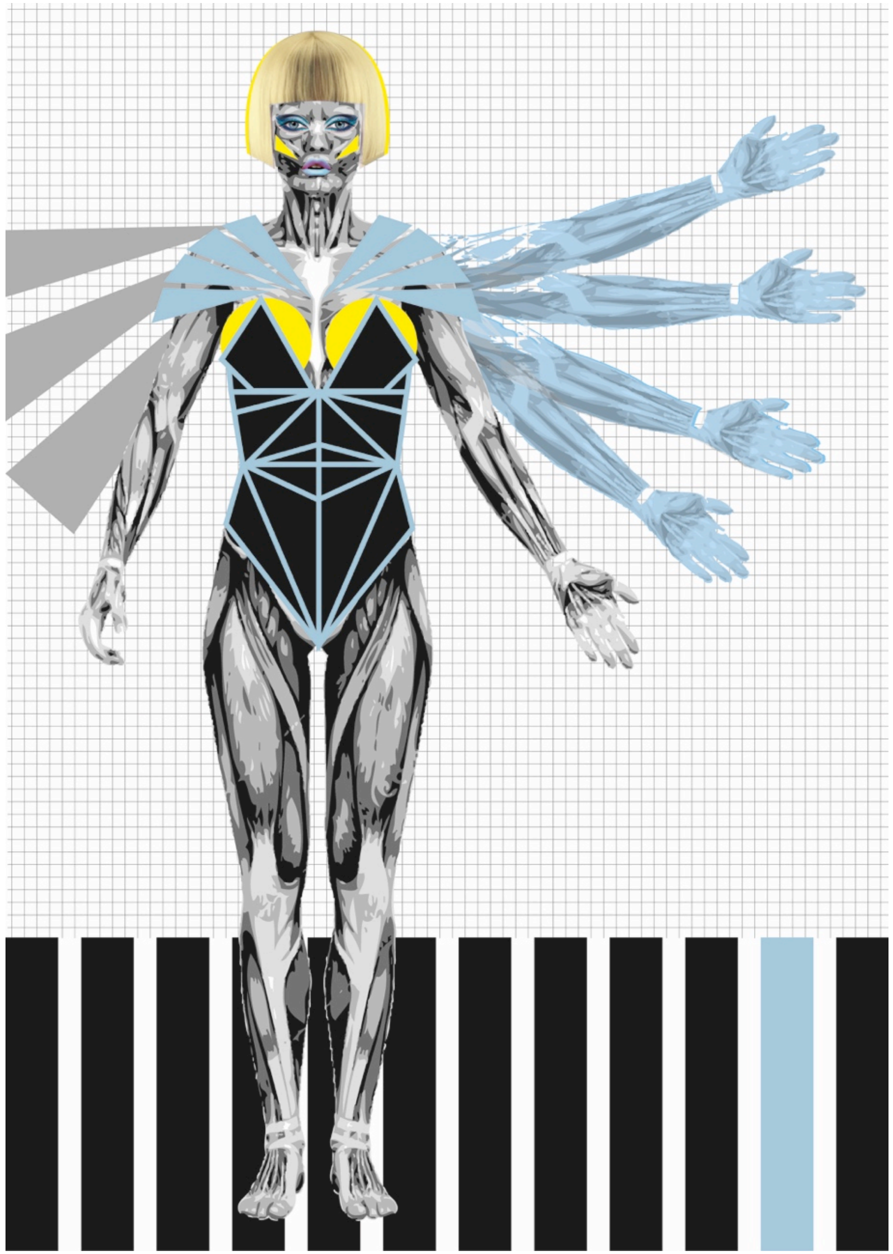

Figure 6 Anna Piper (2015) Mapping Muscles & Movement Visualization.

Within the main body of practice for this project, physical prototypes will be augmented by digital prototypes and concept visualization. 3D scanning, animation and film will be employed to illustrate the phases of construction (from fabric to garment). These technologies will also be used to construct virtual garments and component prototypes; visualizing them as 3D forms located around the moving body (Lindqvist 2015: 137) to demonstrate the kinetic possibilities of the seamless construction and composite garment weaving.

4.2. The Influence of the Method and Mode of Construction on Textile and Garment Design

Textile and garment design and styling is governed by the method and mode of construction. The limited number of shafts[7] on the hand loom places restrictions on the production of different constructions and potential silhouette shaping strategies. Using sectional 'block threading'[8] and 'double cloth'[9] construction, simple geometric shapes can be achieved. Digital Jacquard production affords greater shaping flexibility for the creation of contoured silhouettes and panels. In both cases the warp's pre-determined width and rectangular shape presents a challenge for garment size and volume, as well as for efficient use to minimize waste.

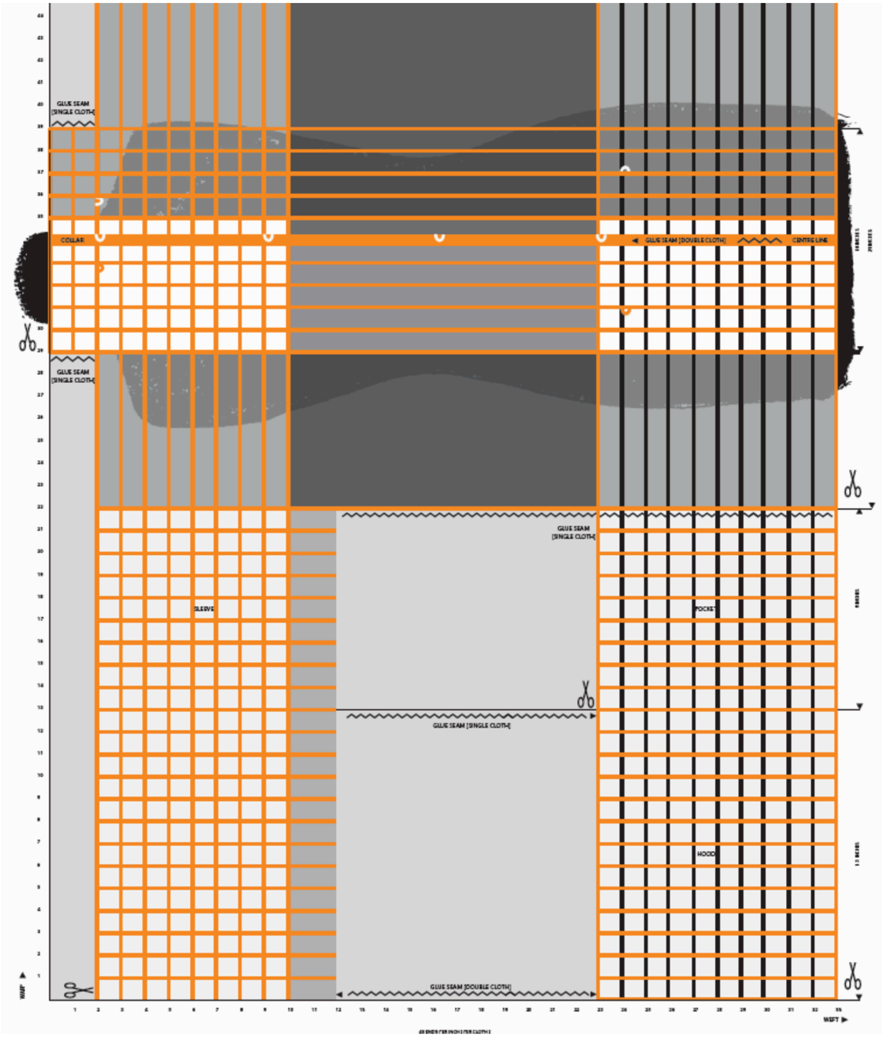

Figure 7 Anna Piper (2013) Section of Jacket Weaving Plan with Tessellating Components.

By adopting the Jigsaw design principle (Rissanen 2013) of tessellating pattern pieces to use an entire piece of fabric, Piper utilizes the unchanging width of the cloth, to minimize warp waste, by producing geometric shaped garments with folding pockets and necklines and detachable components (see Figure 7 – Jacket Weaving Plan). This holistic 'simultaneous approach' (Townsend 2004) challenges the hierarchical fashion system of designing, pattern making, lay-planning and cutting, by integrating 'design and production' more naturally (McQuillan, cited in Gwilt & Rissanen 2011: 85).

Piper's composite garment weaving concept combines elements from a number of Miyake's innovative garment construction concepts. Her textiles and garments, like Pleats Please and 3D Steam Seam, are constructed as oversized 2D pieces that transform into 3D structures when finished (either by washing or steaming). The garment styling and t is inspired by the fluidity, soft lines and semi-structured nature of Miyake's minimalist designs, where fabric and body co-exist (Benaim 1997: 12), as pleats and folds extend and contract to give freedom of movement. In his A-POC range, Miyake exploits the constraints of single piece tubular construction by combining multiple garments in a single tube and working creatively with geometric shapes and simple curves, an approach that is being integrated into Piper's design and construction.

The inherent qualities of woven fabrics, their stability and adherence to folding and pleating, are inspiring and driving ongoing fabric and garment developments. The samples in Figure 8 combine simple weave structures (plain weave and twills), with high twist wools and shrink polyester to pleat and manipulate the cloth. These self-pleating,

Figure 8 Anna Piper (2015) Initial Experiments – Hand Woven Samples

paneling and shaping techniques have been developed and present multiple flexible shaping and fitting options for application to a range of garments. As 3D form and garment fitting is generated through textile construction and composition, yarns and structures are selected for their functionality and shaping capabilities. The complexity of constructing and shaping garments in this way restricts opportunities to assimilate decorative patterns during production.

4.3 Function as a Design Aesthetic

Bauhaus weaver Gunta Stolzl refers to the duality of a woven textile as an assemblage of distinct components and a unified surface (Smith 2014: 67). 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 (Albers 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).

Inspired by Japanese and Modernist design principles functionality forms the basis of the textile design aesthetic within this work. Piper has developed a style that aims to balance functionality and visual impact by celebrating the geometry of woven construction (seen in Figure 9); designs are precise and minimalist. The design style intentionally moves away from the textural, natural, craft aesthetic

Figure 9 Anna Piper (2015) Panel & Stitch Samples.

ordinarily seen in hand woven construction, and frequently when yarn manipulation techniques are used (see Richards 2012 for examples). Adopting a contemporary design aesthetic that assimilates craft and technology, the textiles and garments produced incorporate the technical and utilitarian elements of functional sports fashion including textile and garment features as listed.

Textile Features	Garment Features
• Vibrant accent colours	• Hoods
• Graphic grid-based patterns	• Drawstrings
• Colour-blocking	• Pockets
• Contoured and engineered paneling	• Soft deconstructed tailoring/ shaping

5. Design approaches and production processes: hand and digital weaving

5.1. Production Constraints and Advantages

For hand weaving Piper uses a 16 shaft AVL Dobby Loom with a weaving width of 40 inches. A Bonas Sample Master Jacquard Loom, with predetermined weaving width of 36 inches, is used in digital production. Each production method and machine type has shared and unique restrictions and advantages (outlined in Table 2). Figure 10 demonstrates the primary similarities and differences in the two methods of production. In both, the warp promotes the production of rectangular pieces of cloth, with the loom determining the maximum fabric width[10]. Principles of construction, such as types of weave structure and their relationship with yarns and fabric density, remain consistent across the two modes. Multiple fabrics can be produced simultaneously (layered on top of each other), allowing the front and back of a garment to be woven concurrently.

Figure 10 Anna Piper (2013) Garment Prototypes Showing Differences Between Hand & Digital Construction

	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 structures	• Fixed number of shafts limits structure and pattern combinations and placemen • Garment silhouette (generally restricted to angular geometric shapes
Digital Jacquard weaving	• Single end control facilitates complex structure combination and placement • Single end control facilitate complex garment silhouettes (including curves and contours)	• The looms predetermined tolerances limits yarn usage • Design and structure alterations require reprogramming

Table 2 Advantages and Constraints of Hand and Digital Construction

5.2. The Transition from Hand to Digital Production

When digitizing designs, Piper relies upon her craft knowledge to visualize 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 joining and divisions of the cloth. Technical 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. This mental "reprogramming of the hand", directs the computer to do what the physical body cannot (Taylor & Townsend 2014).

Being trained as a hand weaver, Piper's design ideas are initially filtered and questioned against the 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 capitalize on the capabilities of digital construction; this in turn exposes new possibilities for hand construction, in light of the limitations of the digital technology.

By uniting hand and digital weaving design and production processes, established and advanced technology is employed as a tool without diminishing the maker's role or skilled technique. Hand and digital craft skills are integrated, promoting an exchange of embodied and emerging knowledge to foster new relationships, understanding and a new way of working that pushes the boundaries of 3D weaving practice.

6. Conclusions

This paper reflects on the rationale for research into the design and production of fully-fashioned, woven, composite garments. To date this area of investigation has generally been limited to the production of functional clothing incorporating intelligent technologies and fashion garments featuring "shapeable stretch textiles" (Ng et al. 2010: Wang et al. 2009). By capitalizing on the inherent advantages of woven construction (its stability, adherence to folding and pleating, and multi-functional structures) and adopting a craft-based 'knowing through making' methodology, experimental hand/digital craft weaving techniques have been developed to inform new shaping options for composite garment construction.

Digital Jacquard weaving technologies largely inhibit the direct material and process engagement experienced in hand weaving, which is replaced by a hands-off, non-tactile, largely visual relationship with the screen and machine. By integrating hand loom weaving and digital Jacquard processes, the weave practitioner is able to draw upon the embodied knowledge, craft skills and enhanced technical understanding that can only be derived through the haptic engagement of hand crafting. If primed to 'think digitally' by the machine-mediated experience of hand weaving, it is possible for the weaver to negotiate the transition between manual and digital construction. Concepts, designs and new ways of working evolve as they move between modes and exploit their shared and unique constraints. Just as digitally woven outcomes rely on embodied craft knowledge, this creative experimental strategy relies on knowledge of the digital design and production process to inform the structures and shapes of the hand woven garment prototypes. Hence, each facet is mutually beneficial.

Piper's creative use of digital Jacquard weaving, informed by embodied knowledge of hand weaving and vice versa constitutes a new way of working which subverts the more linear 'hand to digital' route. By taking control of the digital technology and working in harmony with hand crafting Piper is expanding existing zero-waste design practice; offering a strategy for the dual use of available weaving technology which builds on Rissanen's Jigsaw use of the whole width and a bespoke length. The integration of design and production methods and resulting composite garments represent a new sustainable fashion solution (McQuillan, cited in Gwilt & Rissanen 2011: 85).

The methodology illustrates that a platform for innovation, can be facilitated by adopting a transitional (or tandem) approach, supported by different methods of reflection. Employing digital technologies as a tool for inquiry, analysis and reflection (as well as a tool for design and production) offers opportunities to gain greater insights into skill, technique and knowledge-making, providing space for conceptual thinking and experimental prototyping through enhanced understanding of advanced technological production.

Notes

1. Piper studied at Nottingham Trent University (NTU), completing the BA Textile Design course in 2012, specializing in hand weaving, the use of 'Collapse Weave' yarn manipulation and sustainable weaving techniques. Her practice developed to encompass digital Jacquard and composite garment weaving in 2012 during her MA in Textile Design Innovation (completed at NTU in 2013).
2. Pointcarre.
3. In knitwear a single continuous yarn length, facilitates changing widths and greater shaping potential.
4. The looms being used in the research are a 16 shaft AVL Dobby loom and a Bonas Sample Master Jacquard Loom using Pointcarre weave software.
5. Piper's MA collection, 'Fashioning Fit' (2013) included a hand woven dress and jacket, along with half-scale hand and Jacquard woven bodice prototypes. Her BA collection (2012) featured simple hand woven tubular garments (skirts and tops) constructed using Lycra to provide shape and fit.
6. The Jacquard Loom, and its binary coding and mechanization, inspired and was a precursor to the computer. For a short overview of this relationship see Braddock Clarke & Harris. 2012: 9.
7. Shaft limitations: this research is being undertaken on a 16 shaft AVL Dobby Loom.
8. Block threading: threading consisting of different units of warp threads to facilitate the weaving of different weave structures in

(isolated) sections of the cloth.

9. Double cloth construction: uses two warps with specific shafts allocated to each to create two fabric layers. Layers can be woven independently, as a tube, or the cloths can intersect and be joined or ‘stitched’ together.
10. The 16 shaft AVL Dobby Loom has a maximum weaving width of 40 inches. The Bonas Sample Master Jacquard Loom has a predetermined weaving width of 36 inches.

Authors

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