Form from Flat

Exploring emergent behaviour in woven textiles

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Report 2018.6.03

May 2018

Degree Project:
Master in Fine Arts in Fashion and Textile Design with
Specialisation in Textile Design
52DP40

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Abstract

The character of woven textiles is dependent on both the materials and the loom technology used. While digitally-controlled jacquard looms are a major development in weaving technology, they have mostly been used in developing representational and pictorial weaving. Such three-dimensional weaving as exists, utilises materials in predictably similar ways.

Here, through systematic experimentation, three shrinking and two resisting yarns have been combined in multi-layer weaves in order to explore their potential for form-generating behaviour.

Three-dimensional form occurs when the shrinking yarn/s place the resisting yarn/s under tension. To relieve this tension, the resisting yarn moves within the weave, creating waves or folds. The resulting form is highly sensitive to variation, demonstrating emergent behaviour, and identifying the woven textile as a complex system.

Demonstrating the variety of form possible from a limited number of materials, the results represent a small body of work aiming to re-form weaving. The exploration of synergistic material combinations is therefore shown to be an exercise of value to fields from art textiles through to industry. It demonstrates that there is great development potential in woven textiles. Understanding the behaviour of materials is fundamental to furthering form-based weaving.

Key words

Jacquard weaving, three-dimensional woven textile, paper yarn, emergent behaviour, synergistic combination, form, textile design.
Images of results

Figure 1:

*Square*
Cotton, paper tape, linen, elastic
Molded
(Berg, 2018)
Figure 2: 

**Circle**

Cotton, paper tape, linen, elastic
Elastic on the inside or the outside
Steamed
(Berg, 2018)
Figure 3: **Hexagon**
Cotton, monofilament, elastic, remotex
Selectively steamed
(Berg, 2018)
Figure 4:
Line
Cotton, monofilament, wool, elastic
Washed
(Berg, 2018)
Figure 5:  
Rectangle  
Cotton, paper tape, monofilament, linen, elastic  
Untreated, tumble-dried, washed  
(Berg, 2018)
Introduction

Interlacement

A woven fabric consists of threads bound in a pattern (the weave binding): a vertical warp interlaced with horizontal weft (Holyoke, 2013, p.127; Thompson, 2014, p.76). The yarns interlace at right-angles, producing a flat plane. A loom is required to hold the warp threads under tension. The weft is inserted underneath selected raised warp ends.

Simple looms such as the backstrap loom serve only to tension the warp threads, with selection of threads for the binding done by hand. Modern hand and industrial looms both tension and raise warp threads, allowing weaving to proceed much more quickly. However, on shaft or harness looms, the most common, this restricts the patterning to that possible within the number of shafts on the loom (Albers, 1965). Jacquard looms, while less common, enable the weaver to select and raise warp threads individually, returning some of the flexibility of earlier looms (Holyoke, 2013).
Form from the loom

During the 1960s and 70s, the development of three-dimensional loom-woven textiles grew within the broader fibre arts movement (Smith, 2011, p.269), with the aim of "investigating loom-controlled structures which, while woven flat, expand in some way to fill three-dimensional space" (Sherri Smith, 1975, quoted in Waller, 1977, p.124).

Kay Sekimachi’s monofilament hangings (figure 6) were produced during this period. Sekimachi used then-new monofilament in weaves with up to six layers to create self-supporting structures that curve and drape (Waller, 1977; Leventon, 2015). The result is an organic expression, transparent and ethereal - qualities not usually associated with weaving.

Sekimachi’s monofilament work was unique at this time (Mayfield, 2003); most of the sculptural forms of this movement tended towards "the perpendicular geometry of weaving" (Smith, 2011, p.274). This can be seen in some of Sekimachi’s later work (figure 7) which takes the form of boxes that fold into shape once cut from the loom, or Warren Seelig’s pieces (figure 8) in which pleats of double-weave provide form and structure.

Similarly, modern sculptural woven textiles also have this tendency. Lucy McMullen’s Maelstrom (figure 9) is an example, with its layers intersecting at 90 degrees and crisp edges. Despite the spiral format, the overwhelming expression is that of an artificially constructed geometry constrained by right-angles.
The dominance of the right-angles of warp and weft in the expression of woven sculptural form is perhaps best explained by the loom technology in use. Even now, the primary loom available to artists and designers is the shaft or harness loom. This type of loom privileges the horizontal and vertical, but does not lend itself to curves, nor to manipulation of the warp. The structure imposed by the loom limits the expression of the resulting textile (Albers, 2000, pp.56-57).

From the digital to the material

Since the late 1990s, digitally-controlled jacquard looms, both hand- and industrial, have started to become available to artists and designers. Enabling the weaver to control individual warp threads, while retaining the speed of harness looms, layers and patterns can be defined and separated in diagonals and curves (Bang, Trolle and Larsen, 2016). However this has primarily led to a resurgence in figured, pictorial weaving (Holyoke, 2013, p.ix).

Foremost amongst those working in ‘modern tapestry’ is Grethe Sørensen. Her work uses the imagery from digital photographs and video stills. She has developed innovative weave bindings, which, using just eight different colours in the weft, allows her “to create the basic colors and every shade between them” (Bang, Trolle and Larsen, 2016, p.51) (figure 10). Combined with the control of a digital jacquard loom, she can create an intensity and depth of colour in the same way as the computer generates colours on a monitor, or a digital camera captures images, closing the loop between image source and result (Sørensen, 2010).
Unfolding from the loom

Philippa Brock's woven series' Self-Fold (figure 11) and Self-Assembly (figure 12) 'self-form' on being removed from the loom, without relying on finishing treatments save steaming or washing. Brock uses contrasting yarns and fibres - shrinking or elastic yarns to constrict and stiffer yarns to resist - in multi-layer weave structures to create these effects (Hemmings, 2012, p.67). The patterns in the textiles are based on folding and pleating, but with soft, organic lines enabled by the jacquard loom (Crafts Council, n.d.).

By contrast, Aleksandra Gaca's Architextiles (figure 13) have a regular geometric form. Gaca designs explicitly commercial, low-relief three-dimensional textiles aimed at the interior design and fashion markets. She employs a similar approach to Brock in use of materials combined with multi-layer bindings to enable three-dimensionality (TextielLab, 2015, p.64). Geometric motifs organise and structure the designs, creating patterning in their repetition.

Threads in motion

Three-dimensionality in loom-woven textiles, like that in Brock and Gaca's works, occurs when the combination of weave structure and yarn allow the yarn to move within the fabric. For example, tracking, a subtle diagonal texture, occurs in plain weave fabrics woven with high-twist yarns when the direction of twist is the same in both warp and weft (Richards, 2012, p.47). In waffle weave, it is the binding and loose sett that allows the yarns to slide against each other and form a three-dimensional surface (ibid, p.92).

Creating tension

However the most dynamic binding:yarn interactions depend on the relative unpredictability of 'active' yarns: high-twist, elastomeric or other shrinking yarns. Once woven, assuming appropriate weave bindings and sett have been used, these yarns shrink, moving through, against or with the threads binding them (Field, 2008).

Combining strongly shrinking yarns with yarns that are stiff, and resist shrinking, creates tension. If the two types of yarn are placed in two layers within a textile, when the shrinking yarn contracts, it forces the stiff yarn to bend. Depending on the size of the area and the type of yarns, this effect may form a bubble, as in Gaca's textiles (figure 13), or waves, as in Brock's fabric (figure 11).
Wash before first use

While some elastic and shrinking yarns require only steaming to fully activate, other active yarns require wet-finishing. Some, such as wools intended for fulling, must be agitated during the washing process in order to achieve the desired state (Field, 2008). Washing is a critical step during the industrial manufacture of textiles, and may be combined with other finishing techniques to effect the final fabric (Thompson, 2014, p.202). Wet-finishing, then, forms part of the system of woven textiles, in addition to the components of yarn and binding. As such, it is a variable that can impact the resulting form of the textile.

Weaving as synergy

Weaving is naturally synergistic: the combination of thread and weave binding creates something - a fabric - that did not exist in its parts in isolation. The tactile qualities and behaviour of this fabric is determined by the choice of binding pattern, together with the material of the yarn. "For just as silk, a soft material by nature, can become stiff in the form of taffeta, through a certain thread construction, and linen, a comparatively stiff material, can be made soft in another, so an endless number of constructional effects can produce new fabrics" (Albers, 2000, p.33). This combination is synergistic: "As a disorganized heap, they are indeed nothing more than the sum of the parts. But when they are properly organized, they produce a type of synergy ... that the parts alone cannot" (Corning, 2002, p.24).

Synergistic behaviour

Emergence, as a concept, originated in evolutionary theory of the early 20th century, and has since been adopted into the fields of physics, psychology, economics and computer science, among many others (Corning, 2002). In the study of evolution, a key concern is how to explain consciousness and the human mind. Emergence theorists posit that higher-level behaviour, such as consciousness, can arise (emerge) from lower-level structures, such as the interconnected neurons of the brain (ibid, pp.18-19). As this concept has spread to other fields, it has been generalised to describe complex behaviour or characteristics arising from a combination of simple rules or structures, in such a way that the system-level behaviour does not exist within the lower-level parts (Kim 2006; Lewis, 2011; Pearce, 2015). Corning (2002, p.23) has refined this, first by defining synergy as "a whole [that] exists ... when it produces combined effects that the parts cannot produce alone", and then by defining emergence as a subset of synergy - one where the effects of the whole cannot be predicted from the parts.

Thus, emergent behaviour is the behaviour of the system as a whole. Once a synergistic whole is known to exist, it can be observed through experimentation or simulation (Hillis, 1988, pp.187-189). When emergence is observed, the system-level behaviour may be used to extrapolate potential effects in similar systems. Therefore, through experimentation, a map of emergent behaviour in a series of systems can be developed, and it is this process that is described in this thesis.
**Hidden chemistry**

Two artists that work with materials exhibiting synergistic or emergent behaviour are Jaq Chartier and Kate Nichols.

Jaq Chartier creates her ‘Tests’ (figure 14), using inks, stains and dyes. Gradually, and under different chemical conditions within each piece, the colours change and mutate, “interact and respond to each other, to light condition, and to the passage of time” (Chartier, n.d.). Robin Held describes them as “works of fixation and accident” (2004, p.5). These paintings are chemical synergistic systems. That their behaviour is emergent is made clear by Hushka, who states that the “paintings are never finished, and they will continue to evolve. They are not repeatable” (2017).

Also unrepeatable are the paintings of Kate Nichols (figure 15). Nichols works with metal nanoparticles to create non-pigmental colour. “The paint she invented doesn’t actually have any color inherent to it; rather it’s the way that it interacts with light that determines its observed color” (Smithson, 2017). Applied to glass as a solution, the materials bond once the solvent has evaporated. Nichols has learned to anticipate the potential outcome of a piece, but is “often surprised” (Carstensen, 2015) once the piece is finished. She describes nanoparticles as “charged with possibility, ... volatile and likely to produce something new and unexpected” (Nichols, n.d.).

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Figure 14, left: **Jaq Chartier**, *Density Tests (11 Whites)*, 2011
(Chartier 2011)

Figure 15, right: **Kate Nichols**, *Untitled* (silver nanoparticles and graphite on glass), 2017
(Nichols, 2017)
Motive

On seeking emergence

Within the field of woven textiles, producing sculptural forms utilising the potential of digitally-controlled jacquard loom is rare. While loom-based weaving as a method for creating form was privileged during the 1970s fibre art movement (Smith, 2011), contemporary three-dimensional textile art is far more likely to be produced with other techniques, such as crochet or knitting. Despite the form-making potential of the jacquard loom, art weaving has become dominated by the pictorial and the figurative.

While the effects of active yarns in fabrics has been well-explored (Field, 2008; Richards, 2012), the potential of synergistic combinations to create sculptural form in woven textiles through emergent behaviour is an area which could be developed.

Philippa Brock and Aleksandra Gaca’s work in this field is a beginning point for this work. Brock’s textiles (figures 11 and 12) have some form and volume, although dominated by the pattern repeat. This emphasises their status as fabric, rather than sculptural form.

Gaca produces fabrics (figure 13): textiles as products to be consumed through other processes. This sets limits on desirable volume, and emphasises repeatability - both in design-patternning and manufacture.

Utilising the principles of synergistic systems and emergent behaviour to develop three-dimensional woven textiles would expand the potential for weaving in the textile arts, but also produce new knowledge about complex structures and material combinations that could be adapted to the textile industry.

Aim

To explore and understand form-generating emergent behaviour through synergistic material combinations in jacquard woven textiles within the context of practice-led design research.
Design program

Re-forming weaving

The work presented and discussed in this thesis is part of a design program: Re-forming weaving.

As Redström (2017) states, a design program can provide a framework for experimental research in design. Replacing the yes/no dichotomy of hypothesis testing, the design program links and frames a series of related experiments. As the work develops, the experiments and conceptual framework influence each other, with the program setting the initial basis for the experiments, and interesting results from the experiments directing the program's overall direction.

Re-forming weaving consists of four projects: a technical weaving project, Waves, investigating the relationship between weave bindings and form; Woven Specimens, which explored ways of generating form through multi-layer weave structures; Volumes Woven, continuing the work from the previous project, with an emphasis on maximising interior volume; and the project discussed in this thesis, Form from flat. Form from flat takes a more analytical, material-led approach in its exploration, while still aiming to explore the possibilities of sculptural form in weaving.

As re-forming weaving has developed, the focus of the design program has shifted from simply creating new sculptural form through weaving, to wanting to understand the behaviour of the synergistic combinations that make these forms possible. The previous projects in the design program achieved textiles with a large internal volume, and an implicit understanding of the material behaviour that enabled these structures. Form from flat explores the behaviour of a new material, the paper tape yarn, and in doing so, makes explicit an understanding of the behaviour of multiple material combinations.
Waves

As a starting point, this project was inspired by the woven monofilament sculptures of Kay Sekimachi (figure 6), with an aim to develop sculptural weaving as a technique using industrial power looms.

The project explored the effect of different bindings on the resultant form, with a focus on twills. The materials of elastane and black monofilament weft and transparent monofilament warp were not changed, nor was the modified cord binding of the elastic, with the variables being the twill bindings of the monofilament and the proportion of monofilament to elastic. All pieces were steamed until the elastic shrunk to its smallest extent: notably, some pieces responded more to steaming than others.

Here, emergent behaviour is present as distortions in the plane of the weave - ripples, curves and twists. This behaviour is activated by the elastic yarn, but controlled by the bindings interlacing the monofilament weft. The qualities and amount of the distortion varies radically with even small changes in these bindings.

The final piece was woven in order to explore the interaction between three twill bindings that, individually, gave quite different forms. However the scale of the result (at approximately 2.5m long), was such that the weight of the piece was more significant than the effect of the different bindings. This indicates an upper limit on the scale of the emergent effects, due to the relative strength of the yarns used.

A key outcome of this project was the understanding of the limitations of the shaft loom as tool for creating sculptural form. The principle issue lies with the inability to vary the weave structure across the width of the loom, and the restriction in size of potential bindings, which must divide evenly into the number of shafts on the loom. While an attempt was made to weave a multi-layer construction, the sett and slipperiness of the warp, along with the inability to combine a tighter binding with the looser double-layer, meant the the elastic slipped, and was not stretched across the full width of the weave (see figure 32). This significantly reduced the shrinkage and therefore deformation and volume of the resulting piece.
Figure 17:
Exploring the effects of different twill bindings on three-dimensional form

Pieces are hung so that the weft is vertical. All woven on the same loom, the vertical dimension on each piece was the same on the loom (before shrinkage)
Figures 18 & 19, left column:  
3 stripes of herringbone twill, starting and ending with weft-faced stripes

Figures 20 & 21, right column:  
3 stripes of weft- and warp-faced twill, starting and ending with warp-faced stripes

Figures 22 & 23, left column:  
5 stripes of herringbone twill

Figures 24 & 25, right column:  
13 stripes of herringbone twill
Opposite page
Figures 26 & 27, left column:
Vertical twill stripes (each 8 ends wide)

Figures 28 & 29, right column:
Twill squares (each 8 ends and 8 picks high)

This page
Figures 30 & 31, left column:
'Lozenge', modified decorative twill (16 ends by 24 picks high)

Figure 32, right:
Shows shrinkage of elastic weft through warp in double weave, thus not producing distortion of the woven plane
Woven specimens

Working on an industrial jacquard loom, this project had the same aim as the previous project, of developing sculptural form in weaving, but through exploring multi-layer structures. Experimentation was freer, with variations in yarn material, shape, bindings and scale. The only constraints were the warp, of white cotton, and the inclusion of a shrinking yarn (either elastic or pemotex) and a stiff monofilament (black or transparent), with the two weft types used in separate layers at some point within the textile.

It is the combination of these two yarn types that gives three-dimensional form to the synergistic system of the woven textile: the shrinking yarn places the monofilament under tension. Unable to bend, it releases energy through twisting and curling.

A key element was the use of colour, primarily incorporated through additional weft yarns, given the restricted colour palette of black and white in the primary wefts, although an elastic in red was also used.

Most of the prototypes and experiments in this project used geometric patterning with consistent weave bindings, with the intention of developing an understanding of the behaviour of monofilament yarn. Within this framework, two key examples of emergent behaviour presented themselves: In finishing an ‘escaping weft’ piece, it became clear that the position and angle of the iron when steaming fundamentally altered the resulting expression (figure 44). This was tested through steaming each of the four repeats differently. Secondly, a number of ‘sea slug’ pieces were woven, each with small changes in structure (and different colour schemes). However the differences in stability and volume were unpredictable and difficult to relate to the structural changes (figures 45-48).
Opposite page
Figure 34, top:
Final result 2/4: Circles with three layers

Figure 35, bottom:
Final result 3/4: ‘Sea slug’

This page
Figure 36:
Final result 4/4: ‘Escaping wefts’
Figure 37: Final result 1/4: Tesselated hexagons

Figure 38: Final result 2/4: Circles with three layers
Opposite page
Figure 39:
Final result 3/4: ‘Sea slug’

This page
Figure 40:
Final result 4/4: ‘Escaping wefts’
Figures 41, 42 & 43, above, left to right: Experimenting with the effect of scale on three-dimensional form: small to large hexagons, with correspondingly smaller spaces between.

Figure 44, left:
Each column (loom repeat) has the same four different weave bindings stacked from top to bottom. Differences in columns from left to right are due to angle and start position of iron when steaming, which has a significant effect on the final appearance. The large difference in appearance due to small variances is characteristic of emergent behaviour.

Opposite page
Figures 45, 46, 47 & 48, left to right and top to bottom:
The ‘sea slug’ textile began with a mistake (fig 45) when two wefts were woven in the wrong order. The monofilament, intended to be on the outside, is unbound in between the two layers. With an intriguing tactility and movement, it was decided to pursue this further. Figures 46 & 47 show experiments in varying the amount of binding applied to the middle layer of monofilament: 46 with tabby in the centre and no binding at the edges of the repeat, and 47 having the opposite. It was notable that such a small change had such a fundamental change in the form of the woven piece. Figure 48 shows the final textile, which, for the monofilament, has a loose cord binding at the edges of the repeat with tabby in the middle.
Volumes woven

With the aim of developing maximum self-supporting volume, the experimentation here continued directly from the previous project. Similar constraints applied: The same white cotton warp; at least one each of monofilament and a shrinking yarn (generally elastane) in the weft; a multi-layer structure. Prototypes explored the effects on surface and form of textured yarns and new, patterned, weave bindings, along with varying the proportion of weft and warp in the layers of double weaves. Experimentation into the effect of cutting into sections of the textiles were also conducted, and this technique was used in a final piece (figure 50).

This project deepened the knowledge of material behaviours developed through previous experimentation. Emergent behaviour occurred: strongly in those pieces with loose bindings based on basketweave variations (figure 59) where the monofilament weft could escape from the cotton warp; and in smaller tests, where the monofilament weft was less constrained and controlled by the inertia of the textile, and could twist and spiral more freely (figure 58).

Towards the end of the project, experiments were conducted with a paper tape yarn in place of the monofilament. Figures 55 and 56 show two pieces with an identical weave structure, one woven with paper yarn and the other with monofilament. The paper yarn showed a surprising ability to support form, albeit differently from the monofilament, which was unexpected. Large scale tests were also made with the paper yarn (figure 57), but these did not meet the project aim of large self-supporting volume. However, they had a completely new expression compared to the experiments conducted to this point in the design program, and represented the starting point for the work outlined in this thesis.
Opposite page
Figure 50:
Final result 2/3: Cuts/interior

This page:
Figure 51:
Final result 3/3: Form in paper
Opposite page
Figure 52:
Final result 1/3: Hybrid with circles

This page:
Figure 53:
Final result 2/3: Cuts/interior
Figure 54: Final result 3/3: Form in paper

Figures 55 & 56, top to bottom: Identical weave bindings and layout, woven in, left, paper and linen, and right, monofilament and polyamide. The paper version is woven at a looser sett (weft density) due to the width of the paper tape yarn
Figure 57: Large scale test with paper tape yarn

This page
Figure 58, top: Twisting in a small scale monofilament sample

Figure 59, bottom: Monofilament released from the warp, bound in a loose modified basketweave
Method

Exploration of variability

Methods within practice-based design research provide a framework for development of the work. While the method/s should not restrict the work, they guide the direction and give form to experiments, providing a map to the overall path of the research (Hannula, Suoranta & Väden, 2005, p.114). As a method must relate to the context of the research, the aim, and the audience, variations in any of these impact the appropriateness of the chosen method (Mäkelä & Routarinne, 2006, p.16).

The method used for this thesis can be understood as a cycle of three stages (figure 60). During the first stage, research is undertaken in order to understand the emergent behaviour of the woven system (pink circle). This stage is characterised by iterations where prototypes are compared, through a systematic visual evaluation, to a ‘control’ sample, from which they differ by only one variable. This stage is comparable to Jones’s method of Systemic Testing (1992, p.246). Over the course of the work, a model of the system is developed.

The model resulting from the first stage is an initial input into the second stage (green circle). During this stage of the research, the behaviour of the system is manipulated and directed towards an outcome: material-led design. An ideal output from this stage is a design where the result is a direct consequence of the material behaviour, but directed in some specific way. In this stage, development occurs through iterating prototypes, where multiple variables are manipulated simultaneously. Evaluation occurs in comparison to others of the same iteration, with respect to design values and the aim.

In the third stage (blue circle), designs can be considered to be form-led: the work in the two earlier stages allows for an understanding of the material such that its behaviour can be subordinated to the design intent. Unexpected findings or results from this stage may trigger a new phase of the first stage - in the form of material-led experimentation - in order to understand the cause.
Figure 61: The method mapped to Jones's three stages

Jones's model of the design process splits designing into three stages: divergence, transformation, and convergence (1992). These stages map well to the cycle depicted in figure 61. Furthermore, during the green circle stage, this model can again used to understand the process of iterating development used in producing the prototypes. While the process is, here, represented as circular, it is better understood as a hermeneutic spiral, where each iteration of the cycle leads to a higher level of understanding, from which the cycle can begin again (Mäkelä, 2006, p.70).

In this project, key controllable variables include: weave bindings (including compound weaves with multiple layers); weft sett (density); weft materials; scale; and the artwork or layout that determines the positioning and shape of areas of bindings. Given the complex nature of the woven system, it is likely that responses to variable change will not be linear, and that inflection points which cause major changes need to be identified. The intention is to develop an understanding of the potential behaviour of the textile such that not all combinations of variables need to be tested, but only a subset of those that lead to an interesting and useful outcome.

Developing Form from flat

Initial experimentation explored the effects of different manipulations on form. A set of three variations was used. The shrinking weft yarn (elastic) and resisting weft yarn (paper) were the same in all, as was the pattern of weave bindings. The variables were the warp and additional weft material: monofilament warp with linen weft (designated ‘A’ - figure 62); cotton warp with linen weft (‘B’ - figure 63); and cotton warp with wool weft (‘C’ - figure 64). In order to maximise the number of samples, each repeat was separated from the others and treated as an individual sample.

Of note is that the paper yarn was required to be waxed in order to feed smoothly into the loom carrying the monofilament warp. This was continued when weaving with the cotton warped-loom, however it was later evident that this was unnecessary, and was stopped.

The first observation was that the pieces cut from one weft-wise repeat (ie the four repeats next to each other on the loom) were not identical (refer figures 157-159, page 91). This demonstrates emergent behaviour: small variables making significant changes to outcomes. One element of this was related to the specific case of using the resisting and shrinking yarns in different layers within the textile: the pieces at the ends of the strip were able to fold over to release the tension created by the shrinking yarn, while the pieces in the middle were constrained by those around them (this can be seen in figure 218, page 108).

The dyeing experiment (figures 65-70) revealed that the paper stiffened once wetted and dried, and when put through an washing machine cycle would felt where sufficiently loosely bound, and become quite hard. To explore this property, the B sample from the washing machine experiment was dried upside down, in order to cause the paper layer to separate from the elastic layer. Once dry, the piece retained its form against gravity (figure 75).

Significantly, one case which produced a soft but stable form, wetting and tumble drying (figures 80 and 81), was un-reproducible (figures 82 and 83). It is likely that the forms produced in the former set were related to some element of shaping that occurred whilst they were outside and dampened, that was then set when dried.

From this set of experiments, it was decided to not use the monofilament warp further, as it locked the paper into place too firmly, not allowing the deformations seen in the other examples.

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1 As the loom with the monofilament warp has five repeats across its width, compared to the four on the loom with the cotton warp, the artwork file for the A set was adjusted width-wise to fit the smaller width of the repeat, and the height adjusted to compensate for the lower sett (weft density).
Figure 62, top left: 
A - monofilament warp, linen weft. Loom state

Figure 63, top right: 
B - cotton warp, linen weft. Loom state

Figure 64, left: 
C - cotton warp, wool weft. Loom state

Opposite page
Left to right: A, B, C

Figures 65, 66 & 67, top row: 
Washed and dyed with reactive dye. 
The wool became nearly black (C only), while the 
esthetic and monofilament remained uncoloured, and 
the linen, paper and cotton were dyed evenly. It was 
decided not to continue with dyeing, as the result was 
a flat colour, which does not aid in communicating the 
structure or form

Figures 68, 69 & 70, middle row: 
Details showing effects of dyeing process

Figures 71, 72 & 73, bottom row: 
Screen-printed with pigment print paste. Laid on table 
with blank screen laid over the top. This technique was 
not continued further due to the creasing from the 
screen altering the form
Figures 74, 75 & 76:
Top, left to right: A, B
Left: C
Washed at 95°C. Samples A and C air-dried flat, B air-dried suspended upside down

Figure 77, below left:
Detail of felting in paper and wool in sample C

Figure 78, below right:
Detail of felting in paper in sample B

Figures 79, 80 & 81:
Top, left to right: A, B
Middle: C
Left outside in conditions of rain and snow for four days. When retrieved, samples were damp, but otherwise unchanged. Dried in a tumble dryer on cotton setting for approximately thirty minutes

Figures 82 & 83, bottom:
Left to right: B, C
Attempt to replicate form-creation process demonstrated in figures 80 & 81. Samples soaked in hot tap water, drained, then dried in tumble dryer on cotton setting for approximately one hour
Figures 84, 85 & 86:
Top, left to right: A, B
Bottom, left: C
A corner was opened in each sample, and flexible armatures were inserted into the ends of the piece to support it. They were then sprayed with water until thoroughly damp, and left to dry. Once dry the armatures were removed. While the ends where the armatures stood retained their form, the paper softened when wetted and was heavy enough to pull the centre section down.

Interlude
A viscose tape yarn was also tested in place of the paper (figures 88-91), to see if it had similar or other interesting properties. This was deemed unsuccessful, as the tape yarn lost strength when wet and dried (it also had an unpleasant odour when wet). It was decided not to continue with this material, but focus on exploring the properties and potential of the paper yarn.

Figure 87, bottom, right:
Armatures used

Figure 88, top left:
Loom-state

Figure 89, top right:
Soaked in hot tap water, air-dried upside down on 20cm wide board

Figure 90, bottom left:
Soaked in hot tap water, drained, dried in tumble dryer on cotton setting

Figure 91, bottom right:
Washed at 95°C, air-dried flat
Supplementary weft

Colour in three-dimensional weaving can serve to highlight the structure and form of the textiles. Given the use of predominantly white yarns in this project, this includes the tonal effects of white yarns in differing materials, which may be altered through the finishing treatments, or through adding another, coloured, weft yarn.

This set of experiments incorporated colour through a supplementary weft yarn, along with a comparison piece that did not include any additional weft. As with the previous experiments, the weave patterning was consistent, as was the warp (cotton), resisting (paper) and shrinking (elastic) wefts.

The pieces were coded D (linen), E (no additional weft), F (polyester), and G (polyamide). Colours were chosen to be as close to each other as possible in order to focus evaluation on the resulting form.

As can be seen in figures 96-103, the pieces washed at high temperature were tinted pink from bleeding from one of the coloured wefts. A desktop experiment concluded that the linen was the culprit.

While each sample responded slightly differently to the manipulations, no significant differences were noted.

Figure 92, top left: D - linen. Loom state
Figure 93, top right: E - no additional weft. Loom state
Figure 94, bottom left: F - polyester. Loom state
Figure 95, bottom right: G - polyamide. Loom state
Opposite page
Figures 96, 97, 98 & 99:
Top row, left to right: D, E
Second row, left to right: F, G
Washed at 95°C. Air-dried upside down on 20cm wide board

Figures 100, 101, 102 & 103:
Third row, left to right: D, E
Bottom row, left to right: F, G
Washed at 95°C. Tumble dried on cotton setting

This page
Figures 104, 105, 106 & 107:
Top, left to right: D, E
Bottom, left to right: F, G
Soaked in cold tap water, drained, dried in tumble dryer on cotton setting
**Wool-backed**

A set of experiments were conducted with two-layer textiles, where the bottom layer was in wool, with the top layer in paper with a supplementary weft.

As the wool weft is inserted into the textile on the loom, it is held under tension, and stretched. Once removed from the loom, it shrinks a little, giving the undulations seen in figures 108 and 109. The greater variety of texture in figure 110 is due to the polyamide shrinking in the same manner, but more so, putting the paper, which is in the same layer, under pressure.

The arch forms created by washing, then air-drying samples upside down, suspended from a board (see figure 127 for image of samples drying), while strong in some cases (figure 117 especially), showed little room for development and were not continued.

Significantly different textures appeared in the tumble dried samples (figures 111-113). The patterned sample softened and rolled a little, the linen sample folded horizontally, while the polyamide sample folded vertically, forming bubbles of texture.

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Figure 108, top: Wool-backed. Paper and white linen with oval pattern in satin bindings with different float lengths

Figure 109, middle: Wool-backed. Paper and coloured linen, no pattern

Figure 110, bottom: Wool-backed. Paper and coloured polyamide, no pattern
Figures 111, 112 & 113, top to bottom: Soaked in hot tap water, drained, dried in tumble dryer on cotton setting.

Figures 114, 115 & 116, top to bottom: Tumble-dried - details.
Figures 117, 118, 119 & 120, top to bottom and left to right: Washed at 95°C. Air-dried upside down on 20cm wide board

The sample at the top has a smoother form, as the longer floats towards the centre allow the paper to felt, removing excess material (compare to the middle right image)

Figures 121, 122 & 123, top to bottom: Arch forms - details
Mapping materials

A set of experiments was conducted to directly compare the behaviour of the two resisting yarns - paper and monofilament - and the three shrinking yarns - elastic, wool, and pemotex.

Rather than producing tests with two layers separated across the width of the textile, as had been extensively tested, a layout of tessellated hexagons was used. A border around each hexagon was woven in a single layer, while the hexagons themselves contained a two-layer weave binding. The back layer binding was consistent, but the top layer binding was one of six satin-based bindings with increasing float lengths. All six bindings were used, distributed amongst the hexagons in the layout.

In order to test each shrinking yarn in both top and bottom layer, paired with each of the other two shrinking yarns, six samples would be required. Combined with two resisting yarns, a total of twelve test weaves would be required. Given that this quantity would be unreasonable to weave, a cycle of three combinations of the shrinking yarns was developed. This paired each yarn with both of the others, while also ensuring each was woven in both the top and bottom layers.

Each set was woven with both paper and monofilament resisting yarns, and the four treatments of washing, drying, steaming or none (loom state) was applied to each, giving 24 individual samples, shown in figures 128 to 151.

While the results do show many similar outcomes across sets, they clearly illustrate the difference responses of the monofilament and paper yarns to tension and the various treatments.

An unusual set of forms is created in samples U and X when steamed. With elastic in the top layer, and pemotex in the bottom, in loom-state the samples lie fairly flat, the shrinking of the elastic restricted by the resisting yarn. Under steaming, the pemotex shrinks, which induces the resisting yarn to curve away. However the elastic shrinkage is enhanced by steaming. This results in significant buckling in areas of loose binding, where the resisting yarn can bend away from both shrinking yarns, and curvature in areas of tighter binding, where the elastic remains constrained by the resisting yarn.

Note: all captions in this section state the resisting yarn first, followed by the shrinking yarn in the top layer, then the shrinking yarn in the bottom layer.
Figure 128, top left:
Q - paper, wool, elastic. Loom state

Figure 129, top right:
Q, steamed

Figures 130 & 131, bottom row:
V - monofilament, wool, elastic. Two samples from the same piece, both loom state. The other two samples resembled the one on the left before treatment. There was no obvious reason for the sample on the right to have a different form.

Figure 132, top left:
Q, washed at 95°C, air-dried flat

Figure 133, top right:
Q, soaked in hot tap water, drained, dried in tumble dryer on cotton setting

Figure 134, middle:
V, washed at 95°C, air-dried flat

Figure 135, bottom:
V, soaked in hot tap water, drained, dried in tumble dryer on cotton setting
Figure 136, top left:
T - paper, pemotex, wool. Loom state

Figure 137, top right:
T, steamed

Figure 138, bottom left:
W - monofilament, pemotex, wool. Loom state

Figure 139, bottom right:
W, steamed

Figure 140, top left:
T, washed at 95°C, air-dried flat

Figure 141, top right:
T, soaked in hot tap water, drained, dried in tumble dryer on cotton setting

Figure 142, bottom left:
W, washed at 95°C, air-dried flat

Figure 143, bottom right:
W, soaked in hot tap water, drained, dried in tumble dryer on cotton setting
Figure 144, top left:
U - paper, elastic, pemotex. Loom state

Figure 145, top right:
U, steamed

Figure 146, middle:
X - monofilament, elastic, pemotex. Loom state

Figure 147, bottom right:
X, steamed

Figure 148, top left:
U, washed at 95°C, air-dried flat

Figure 149, top right:
U, soaked in hot tap water, drained, dried in tumble dryer on cotton setting

Figure 150, middle:
X, washed at 95°C, air-dried flat

Figure 151, bottom:
X, soaked in hot tap water, drained, dried in tumble dryer on cotton setting
Opposite page
Figure 152, top left:
V - monofilament, wool, pemotex. Full width weave and no borders between repeats. Washed at 95°C, air-dried suspended

Figure 153, top right:
V. Borders between repeats, two repeats (half loom width). Washed at 95°C, air-dried suspended

Figure 154, bottom:
V. Full width weave and no borders between repeats. Loom state

This page
Figure 155, left:
V. Full width weave and no borders between repeats. Washed at 95°C, air-dried suspended. Detail

Figure 156, right:
V. Borders between repeats, two repeats (half loom width). Washed at 95°C, air-dried suspended. Detail
Building a skeleton

An experiment to alter the form of a simple, multi-layer textile, using monofilament as a structural element, was conducted.

Consisting of four variations - two with three layers: one with monofilament in the middle ('H’ - figure 160), and elastic on the bottom; one with elastic in the middle, and monofilament on the bottom ('Y’ - figure 163). Two with two layers, where in each case the monofilament and elastic are striped on the bottom layer.

The first of the two layer pieces was woven with the elastic and monofilament transposed ('I’ - figure 161) from where they had been intended, hence weaving a second piece with the wefts as planned ('J’ - figure 162). These pieces had five stripes on the bottom layer, with three stripes in satin, and two stripes in herringbone twill. As planned, the elastic wove in the satin areas, and the monofilament in the twill. In the case of the three layer samples, the monofilament was bound in plain weave, while the elastic was in satin.

All have a top layer of paper and a coloured linen, to make the form clearer, and distinguish one sample from another. This layer has areas in multiple satin bindings with differing float lengths. I, J and Y use the same pattern layout for the top layer, while H has a different layout, which may account for the different form produced in the tumble-dried sample (figure 164).

Sample Y displayed very different behaviour from the others in this series when washed and tumble dried. One variable contributing to the resulting form may have been that Y was produced at a later stage of the project, and the samples were washed and dried individually, whereas the other sets were washed and dried together.

Figures 157, 158 & 159, top to bottom:
Three samples cut from one four-repeat wide woven piece. Note the selvedge visible in the middle image. They have identical weave bindings, layout and yarn, yet variables such as the different tension in the middle of the cloth beam versus the edges means they have produced quite different forms.
Figures 160, 161, 162 & 163:
Left to right, and top to bottom
Loom-state examples of:
H - three layers, monofilament in middle, elastic on bottom
I - two layers, bottom layer three stripes of monofilament, two stripes of elastic
J - two layers, bottom layer three stripes of elastic, two stripes of monofilament
Y - three layers, elastic in middle, monofilament on bottom

Figures 164, 165, 166 & 167:
Top, left to right: H, I
Bottom, left to right: J, Y
Soaked in hot tap water, drained, dried in tumble dryer on cotton setting
Figures 168, 169, 170 & 171:
Top row: H
Bottom row: I
Washed at 95°C, air-dried flat

Figures 172 & 173, top row:
J - washed at 95°C, air-dried flat

Figures 174 & 175, bottom row:
Y - washed at 95°C, air-dried suspended vertically
A series of tubes

The armature experiment (figures 84-86, p.68) was considered unsuccessful due to sagging in between the supports. It was decided to try using a solid mold instead. A sample from the Volumes Woven project (figure 176) was used: a rectangle closed on all four sides, with a top layer of paper and linen, and bottom layer of pemotex. Both ends were opened, it was soaked in boiling water, then molded around a tube with a similar circumference and left to dry. Once dry, the tube was removed and the form proved stable (figure 178).

A further test with a similar sample, but three times the length, pleated on to the same length of tube, proved even more successful, with a bouncy, playful quality to its movement (figure 191, p.100).

A set of open-ended rectangles were woven, with both top and bottom layers the same, and different qualities of elasticity and weave bindings. Three repeats were sewn end-to-end, and this was molded on a tube of appropriate circumference. The results are shown in figures 179-186.

Collapsing forms

While the unstable nature of some of these experiments gave an unusual, organic form, the intent was to find a way to showcase the potential stability inherent in the paper yarn. For this reason, a test was conducted with a tube with a square cross-section (figure 192), to see if this was less prone to collapse. Compared to the circular tube (figure 191), this was a significant improvement, and the next stage of experiments exclusively used the square tube mold.

Figure 176: Holding form (see page 105)

Figure 177, left: Original piece, steamed to activate pemotex

Figure 178, right: Opened and molded over cylinder
Opposite page
Figures 179 & 180, top row:
Vertically striped twills, no elastic, 70cm tube

Figures 181 & 182, second row:
Horizontally striped twills, polyamide on inside, 60cm tube

Figures 183 & 184, third row:
All over decorative twill with central stripe of basketweave. Elastic on inside, 50cm tube

Figures 185 & 186, bottom row:
All over modified twill, elastic on outside, 44.5cm tube

This page
Figures 187, 188, 189 & 190, top to bottom:
Corresponding details of surface after molding process.
Figure 191, top:
Sample molded over cylindrical tube

Figure 192, middle:
Sample molded over tube with square cross-section

Figure 193, bottom:
Square sample formed into round

Figure 194, top:
A sample in loom state

Figure 195, middle:
Drying on the mold

Figure 196, bottom:
Dried and removed from the mold
This page
Left side: molded; right side: loom state

Figures 197 & 198, top row:
Three densities of colour - one to a side

Figures 199 & 200, middle row:
Herringbone twill pattern, with textured yarn surface

Figures 201 & 202, bottom row:
Modified twill with lurex yarn

Opposite page
Left side: molded; right side: loom state

Figures 203 & 204, top row:
Smoothly coloured outside

Figures 205 & 206, bottom row:
Coloured inside, with corners woven in (note that they are not quite in the right position relative to the mold's corners).

This piece showed the most promise for creating a stable form, with the advantage that the woven-in corners facilitated the form - so that the mold was less about forcing the textile into a shape, but about facilitating the stability of the existing form. The next set of experimentation followed this path.
**Holding form**

*Holding form* was designed to showcase the strength and resilience of the paper yarn once wet-molded. It was woven 6m long, and compressed during molding to 1.5m. The two tubes are woven side-by-side, and joined for the first 30cm, before separating. The piece retains its shape: stiff, yet soft. With no additional internal structure, it can support the weight of another section crossing it.

Left side: molded; right side: loom state

Figures 207 & 208, top row:
Blending colours on outside

Figures 209 & 210, middle row:
Colour inside and outside

Figure 211:
Colour on inside only
This is the version used for the piece Holding form. The internal colour differentiates the inside and outside, while the paper - the material to be showcased - is clearly visible on the outside

Figure 212:
*Holding form*
Cotton, paper tape, polyamide, elastic
Divergent forms

Two alternative forms were created: one with irregular folds (figure 213), and one with no elastic and two folds per side, to be molded on a hexagonal form (figures 214 and 215).

In the case of the former, it was clear that more folds would be required to release the tension on the paper, as unplanned creases had appeared.

The hexagonal form was unstable due to the internal angles, which encouraged the lower layer to collapse.

In search of stability

A last set of experiments with the tubes incorporated valley folds (folding to the inside of the tube), then patterning the folds across the paper layer (refer figures 216-220). While this showed an increase in stability, without molding the pieces are still prone to collapse when not supported on both sides. This is an area that could be explored further in some future work, but it was decided that Holding form represented the most stable form presenting this aspect of the paper yarn, and that the tube experimentation should not continue.
Figure 216, above:
Adding valley folds to the edges of the top layer (white stripe on the inside)

Figure 217, left; figure 218, below:
Removing the parallel mountain folds on the top layer and replacing with mountain and valley folds in a diamond pattern increases the stability of the form. Note that the repeats on the edges still collapse

Figure 219, top:
Halving the height of the diamonds further stabilised the form. The weaving has been moved over half a repeat. This means there are three complete tubes, and two half tubes on the edges. The half tube on the right has been cut, separating the two layers. This is allowing the complete tube on the right to lean to that side. The layers of the half tube on the left are still joined by the selvedge

Figure 220, bottom:
As above. Note the more circular shape at the mouth compared to figure 217 opposite
Emergent folds

While doing an early tube experiment (figure 185, p.98), it was noticed that the four repeats across the width of the piece had different fold patterns, despite being nominally identical. This is a clear example of emergent behaviour, where the synergistic system is sufficiently complex that subtle changes produce significant changes in the outcome. In this case, the synergistic system is the textile sample, which consists of the yarns, the weave bindings, warp and weft density, and other variables such as cloth and warp beam tension, and even humidity and temperature.

The folds occur because the elastic, woven in a loose satin binding, shrinks. This puts the paper, woven in a modified twill binding on the other side of the same warp ends, under tension. Once the shrinkage exceeds the limit of the paper yarn’s resistance, it bends away from the elastic, creating a fold and relieving the tension. Steaming creates deeper folds, but not new ones (compare figures 224-226 with 227-229), as the increased shrinkage of the elastic forces additional paper yarn towards the bend, and away from the elastic.

Figures 221 and 222 show two un-cut samples of the elastic-outside tube piece from figure 184, which were woven at different times. They show clearly the different sets of folds both across the width, but also between the two samples.

Figure 223 shows a similar piece, but woven without the single-layer bindings between each repeat. Again, the folding is uneven, but it starts to show a regularity as the tension on the paper is distributed evenly across the whole width of the piece, uninterrupted by the tighter, single layer, bindings.

Figures 224 through 233 show variations woven in an attempt to understand variables affecting the pattern of folding. Yarn, weave bindings and weft sett were controlled, while the pattern dictating the location of the bindings was changed.

This approach did not find any controlling variables relating to pattern. All these samples show folds of similar density and size, although, again due to the complexity of the system, all have different specific patterns.
Figure 224, top:
Smallest separation between repeats - 1.5% of two layer section. Loom state

Figure 225, middle:
20% separation between repeats. Loom state

Figure 226, bottom:
Largest separation between repeats - 40% of two layer section. Loom state

Figure 227, top:
1.5% separation. Steamed

Figure 228, middle:
20% separation. Steamed

Figure 229, bottom:
40% separation. Steamed
Figure 230:
40% separation. Steamed. Detail

Figure 231, top:
Hexagon pattern, open-ended. Steamed

Figure 232, middle:
Circle pattern, closed. Steamed

Figure 233, bottom:
Twin triangles pattern. Top open and bottom closed. Steamed
New variables

Four new weave bindings were tried in the two-layer section. The elastic remained on top, in a loose satin binding - the new bindings applied only to the paper and linen underneath. These were woven within a closed circle, as the previous experiments had shown that to be the most effective at displaying the difference between the two-layer folding section and the single-layer border. They were also kept as a single textile, unseparated, to test the effect of this for a potential final example. While the weave binding was changed, the yarns and weft sett were once again kept consistent.

As is evident in figure 234, changing the bindings did not have a significant effect on the appearance of the folds.

Two further samples were made. One reversed the weave bindings such that the paper and linen were on top with the elastic below (figures 235 and 237), while the other had the second layer removed, so it was woven as a single layer cloth (figures 236 and 238).

The single layer piece was largely flat, with creases primarily from handling. It did not respond to steaming, as the tightness of the bindings no longer allowed the elastic to shrink. This was because removing the second layer effectively caused both the warp and weft sett to double in this area. Attempting to induce some sort of change, this piece was soaked and tumble-dried (figure 239).

The elastic-inside piece however, does appear quite different. This occurs because the paper yarn needs to bend away from the elastic - in previous samples it bends to the inside, here to the outside. It is the same effect, but a different expression (compare figures 240 and 241).

Given that a large number of samples had found no significant change in expression, it can be concluded that the primary variable controlling this effect is the relationship of the elastic to the paper. Weave density is also a factor, but further experimentation would be needed to determine whether this variable has an inflection point - where the change is from on to off, ie unfolding to folding, or has a gradual change affecting the appearance of the folds.

Figure 234:
Weave bindings top to bottom:
Square herringbone twill
16-shaft right twill
Breaking weave #761 (Oelsner, 1915, p.165)
Crepe weave #897 (Oelsner, 1915, p.183)
This page
Figure 235, top:
Sample woven with elastic on inside. Loom state

Figure 236, bottom:
Sample woven in single layer. Loom state

Opposite page
Figure 237, top:
Elastic inside. Steamed

Figure 238, middle:
Single layer. Steamed

Figure 239, bottom:
Single layer. Soaked in hot tap water, drained, dried in tumble dryer on cotton setting
Figure 240:
Elastic on the outside - detail

Figure 241:
Elastic on the inside - detail
Results

Square

Cotton, paper tape, linen, elastic.
Molded.

The paper tape yarn, when wet, pleated and dried on a mold, hardens to support its own weight.
Circle

Cotton, paper tape, linen, elastic.
Elastic on the inside or the outside.
Steamed.

The paper tape yarn releases tension by curving, then folding away from the source of tension.

Figure 245, left: Circle, elastic on the inside - detail
(Berg, 2018)

Figure 246, right: Circle, elastic on the outside - detail
(Berg, 2018)

Figure 247, top left: Cross-section of Circle. Two layers, elastic on the inside and paper and linen on the outside of both layers.

Figure 248, bottom left: Cross-section of Circle. Two layers, elastic on the outside and paper and linen on the inside of both layers.

Figure 249, right: Drawdown of weave binding used for the paper and linen in Circle
Hexagon

Cotton, monofilament, elastic, pemotex.
Selectively steamed.

The monofilament yarn releases tension by curving away then towards the source of tension.

Figure 252, left: Cross section of a hexagonal element in Hexagon. Two layers, top of monofilament and elastic, bottom in pemotex

Figures 253, right: Cross section showing the effect of steaming: the pemotex in the bottom layer shrinks, forcing the monofilament up to release the tension
Line

Cotton, monofilament, wool, elastic.
Washed.

*If the tension is too great to be relieved by forming waves, and the weave is loose enough, the monofilament yarn releases tension by spiraling against itself.*

Figure 254: Line - detail (Berg, 2018)

Figure 255, left: Weave artwork of one warp-wise repeat of Line showing distribution of satins of decreasing density (light to dark). Seven repeats were woven and sewn end-to-end (weft-wise) before washing.

Figure 256, top right: Cross section of a hexagonal element in Line in loom-state. Two layers, top of monofilament and wool, bottom in elastic.

Figures 257, bottom right: Cross section showing the effect of washing: the wool in the top layer shrinks, forcing the monofilament out of the weave binding and into a spiral in order to release the tension.
Rectangle

Cotton, paper tape, monofilament, linen, elastic.
Untreated, tumble-dried, washed.

The monofilament, resisting, can constrain the shrinkage of the elastic, while the paper tape yarn outlines the form.

Two layers, paper tape on top, monofilament and elastic striped in bottom
Three layers, paper tape on top, elastic in middle, monofilament on bottom
Three layers, paper tape on top, monofilament in middle, elastic on bottom

Untreated

Tumble-dried

Washed

This page
Figure 258:
Material and treatment combinations in Rectangle

Opposite page
Figures 259 - 267:
Rectangle - details
Discussion

Throughout this project, the aim has been to explore the form-generating behaviour of woven textiles. An iterative, experimental approach, defined through a model incorporating material-led experimentation, material-led design, and form-led design has been used in order to understand these complex synergistic systems.

For the final result, a series of examples that demonstrate new expressions of form generated through manipulation of material, binding and treatment are presented. These represent a potential expansion of the field of three-dimensional woven textiles, both by demonstrating new forms, as well as illustrating the behaviours responsible for those forms.

Just as one can never cross the same stream twice, one can never weave twice on the same warp. Tiny variations in take-up and tension transmit themselves into the weave, impacting the finished textile in ways that simply cannot be controlled. These elements have inflected the folds and waves of Circle. This suggests there may be some new way of understanding or further working with these variables.

In contrast, Square uses the same combination of materials - paper tape, elastic and linen - and presents a controlled form. Through separating the resisting and shrinking materials in different layers, combined with the propensity of the paper tape to hold form when wet-molded, this piece demonstrates the strength and resilience of the paper in a three-dimensional structure.

Whereas Circle and Square demonstrate behaviours of the paper tape yarn under tension, Hexagon uses a monofilament-based weave to contrast the behaviour of two shrinking yarns. While a paper-based twin was woven, it did not add any new understanding, and obscured the connection to Line.

A companion piece to Hexagon, Line takes the behaviour of monofilament under tension to its limit: by changing one of the resisting yarns to a feltable wool, and washing the piece, its length is reduced to half. The monofilament, unable to shrink, explodes from the weave in twists and curls, causing the underlying structure to spiral. Tightly woven, non-shrinking, sections are included at intervals along the length, pleating in response to the tension surrounding them. Setting up a rhythm of structure and chaos, they demonstrate the range of responses of a monofilament-based weave to shrinkage and tension.
The following stages, of material- and form-led design, can be characterised as iterative, experimental design processes. However the understanding and knowledge built in the former stage allows for a deeper exploration of form when designing, less reliant on serendipity.

In textile design, an understanding of the behaviour of conventional materials exists as implicit knowledge within the field. This base of knowledge does not yet exist for the active combinations of resisting and shrinking yarns required to generate three-dimensional form from a flat-woven textile. At best, a tacit understanding has been developed by those who have worked with these materials in the past. Until such time as this knowledge is fully developed and embedded within the field of woven textile design, the three-stage method allows designers to rapidly understand the behaviour of their materials.

This thesis, therefore, explicitly identifies and encodes this tendency for variability as emergent behaviour within a complex woven system. By defining this behaviour, and demonstrating its effects, this work presents a framework and methodical way of thinking and working for a field that is often reliant on serendipitous occurrences.

Of these pieces presented as final results, the collection that makes up Rectangle presents the most variation in form, yet is least developed. As suggested by the title, each piece is a multi-layer rectangle, joined on all sides. Simple changes to this formula, such as altering the shape, or modifying the relative densities of the layers of shrinking and resisting yarns, could fundamentally alter the finished form.

The experiments in Form from flat push the limits of machine weaving. Paper pieces build up in the knife, preventing the other wefts from feeding correctly. Or monofilament too tough to cut cleanly develops barbs, catching on everything, breaking wefts and causing inumerable stoppages. Areas of uneven warp take-up lead to cotton stretched taut like steel cable at the back of the loom.

All of which points to another potential development of this work: modifying the materials and the weaves to be easier on the loom. Form from flat deliberately contrasts vastly different yarns: thin, springy elastic with thick, resilient monofilament or tough paper tape. Simply replacing each of these, perhaps a thicker elastic, a thinner monofilament, could create new works, new forms, and new findings.

A woven cloth and the loom it is constructed on are a complex system. Minute variations in warp tension, or the tension on the cloth beam, may not affect a flat cloth of simple construction. However, in a woven system controlled by active yarns, each inconsistency is amplified, with minor differences in construction giving rise to significantly different forms. That creating this type of three-dimensional woven textile is subject to variation and complexity is known, if not perhaps understood. Philippa Brock, for example, notes that her designs rely on “a certain amount of serendipity” (quoted in Hemmings, 2012, p.67).

In order to understand these complexities and serendipities, the method outlined on pages 61 and 62 was developed. Of particular importance to developing an understanding of material behaviour was the first stage: material-led experimentation. Freeing the work from a need to produce a ‘finished’ outcome enabled variables to be examined and manipulated in a structured way. Comparing results against a baseline sample with only a single variable of difference allowed for identification of material behaviours that could be manipulated, along with emergent behaviours not subject to control.
Reference list


Image references

Except as noted below, photographs and figures are by the author

Amiyose III [photograph online]. Available at: http://collections.museumca.org/?q=collection-item/20041091 [Accessed 28 February 2018].

Berg, J., 2018. Square, Circle, Hexagon, Line, Rectangle, Circle (elastic on the inside - detail), Circle (elastic on the outside - detail), Hexagon (detail, unsteamed), Hexagon (detail, steamed), and Line (detail) [photographs].


