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Emergent behaviour as a forming strategy in craft: The workmanship of risk applied to industrial-loom weaving

Abstract
Digital tools such as CAD/CAM have expanded the nature of craft practice, offering new means of design and making. However, in weaving, hand-making continues to be privileged, despite acceptance of digital design and computer-controlled lifting mechanisms. Through experimental design research methods, self-forming three-dimensional textiles were designed in CAD software and woven on a computer-controlled jacquard power-loom (a CAM tool). The textiles' three-dimensionality arises from the combination of materials (contrasting shrinking and stiff yarns), structure, and finishing. They are contextualized as craft objects through Pye's concept of 'the workmanship of risk'. As outcomes of a craft process, they illustrate the potential of industrial looms as tools for producing complex textile systems and expressions. The results include a method for crafting at the intersection of the workmanship of risk and CAD/CAM, providing a framework for this hybrid practice. The concept of emergent behaviour is discussed as a craft strategy when the workmanship of risk is focused on material forming rather than tool or technique. This concept is contextualised beyond weaving, suggesting its applicability to other craft fields and practices, whether produced by hand or with the use of digital tools.

Keywords:
craft research
jacquard weaving
3D textiles
digital fabrication
CAD/CAM
woven textile design
emergent behaviour

Introduction

Craft, and craft practice, have been defined in many ways, from Risatti's hand-made 'objects [that] are self-contained, self-reliant' with a function 'typically concerned with preservation and stasis' (2007: 46), to Adamson's definition of craft as a process, 'a way of doing things […] organised around material experience' (2007: 4). However, David Pye's ([1968] 2010) definition of craft practice as that which incorporates 'the workmanship of risk' is used to discuss the potential of the industrial jacquard loom as a tool for craft research in textile design. This paper describes a research practice where experimentation adopts the tools of industrial processes, to develop a new perspective on what crafting could be in weaving today.

As a definition of craft practice the workmanship of risk emphasises the judgement and skill of the crafter, as they engage with materials, tools, and techniques to produce craft artefacts (Pye [1968] 2010). In weaving, a crafting technique in the field of textile design, the workmanship of risk prioritises handwork engaging with the tactility of its materials (Albers 1965). The increasing availability of digital and automated tools for textile processes alters the means of design and making in what is nevertheless a fundamentally haptic craft. This paper presents experimental textiles crafted through a process of digital design and automated weaving and discusses them in relation to the workmanship of risk and the potential of industrial tools for crafting complex textile systems and expressions.

Pye places craft and mass production in opposition through the twin concepts of the workmanship of risk, and 'the workmanship of certainty' ([1968] 2010: 4). The workmanship of risk emphasises the 'care, judgment, and dexterity' of the crafter (Pye [1968] 2010: 24) to avoid adverse outcomes or mistakes. Thus craft practice possesses a responsiveness to flaws of both making and material, enabling the crafter to design within and alongside the process of making. In contrast, mass production aims to reproduce identical objects in great numbers, requiring uniformity of both process and material. The human engagement in mass production is with the machine, ensuring it is supplied and running smoothly (Penny and Fisher 2021).

In the creative process, craft practitioners engage with materials, tools, and techniques to produce artefacts (Loh, Burry, and Wagenfield 2016). Craft artefacts are typically one-off, or if part of a series, may bear the marks of tools, such that they are non-identical or irregular. This implies a uniqueness of effort, time spent working on a single item, reflected in its aesthetic. Pye uses the terms 'free workmanship' and 'regulated workmanship' to define a spectrum for the appearance of a craft artefact. Free workmanship may seem unfinished, bearing evidence of its making such as tool marks. Regulated workmanship, by comparison, is absent of such traces, appearing closest to the ideal of the design (Pye [1968] 2010: 17). While craft artefacts may span this spectrum, mass produced items are expected to be regulated and perfect in their aesthetic, produced without trace of human input. The skilled crafter, therefore, is expected to hone their technique to produce artefacts that are well-made, but which bear the individual traces of their making (Dormer 1997; Foote 2017).

Dormer (1997) defines the core of craft as tacit knowledge, the experience and understanding of doing. He notes the continuum that links the hand-woven 'craft-shop' one-off and factory production of woven textiles, but nevertheless conflates craft with 'handmaking' (Dormer 1997: 174). Within the field of weaving, developing tacit knowledge is considered the domain of handwork engaging with the tactility of materials (Albers 1965; Philpott 2012; Piper and Townsend 2015). Stoltz wrote that woven textile design must take place on a handloom to have 'enough room to play, to develop an idea from one experiment to the next' (1926, quoted in Smith 2014: 64). Yet all looms are tools which mediate the interaction between weaver and material (Piper and Townsend 2015). Even as digital design tools and computer-controlled lifting mechanisms are accepted, broadening the design possibilities available for hand-weavers (Bang et al., 2016), industrial looms are considered tools of the workmanship of certainty, ones that limit 'the possibilities of innovation through intervention' (Piper 2018: 53): they are seen as offering insufficient freedom for crafting in the workmanship of risk.

However, the inclusion of computer-aided design and manufacturing (CAD/CAM) tools in craft practice has been gaining acceptance over the last two decades (Walters and Thirkell 2007; Song 2021). Digital production requires deep understanding of material behaviour, as in handcrafts, but also knowledge and expertise of the tool itself (Celento 2009; Hansen and Falin 2016). While these processes may have originated as tools of the workmanship of certainty, adopted into craft practice they 'often involve [...] risk and uncertainty, particularly by inviting serendipity into the process' (Celento 2009: 105). In the experimental textiles presented in this paper, this serendipity arises through what I call 'emergent behaviour'.

Crafting woven systems: From digital design to physical manifestation

The digitalisation of design requires new skills in understanding and navigating software that may impose a specific sequence, and particular ways of thinking (Dormer 1997: 146). Similarly, automated tools such as industrial looms require new skills to operate, distinct from those of hand weaving, and may require certain ways of working. Nevertheless, the need for an understanding of the fundamental logic of woven structures and material characteristics remains unchanged. The digital environment for weavers in software such as Scotweave is pristine, full of ideal yarns interlacing perfectly. Upon entering the physical realm, the weaving process does not always proceed as smoothly as digital simulations suggest, while the crafter may discover during or after weaving that their materials contain faults or flaws. The skill of a designer or crafter is to understand and overcome the digital/physical divide: to envision the material and aesthetic outcome.

There are two types of computer-aided manufacturing (CAM) in weaving. In a computer-controlled hand loom the shafts to be raised are determined by a lift plan file. Weft insertion via shuttle, beating (packing the weft yarn in), and advancing the cloth, are all controlled by hand. This frees the weaver to improvise and adapt weft yarn and fabric density during weaving. Power looms (industrial looms) raise warps, select and insert the weft, beat, and advance the cloth automatically. Regardless of loom type and mode of operation, many of the creative choices are likely to have been made during the design phase, due to the nature of the woven textile: ‘Weave structure, yarn properties, fabric density and the influence they have on each other all have to be understood and carefully balanced’ (Piper and Townsend 2015: 11). Weave structures, the specific patterns of yarn interlacement, such as plain weave or twill (Alderman, 2004; Shenton, 2014), are here referred to as ‘bindings’, while the term ‘structure’ is reserved for the macro scale elements of the textile, such as layers and density.

Textiles are systems consisting of a hierarchy of material and construction sequences, beginning with the fibre/s and construction of the yarn. Thus fibre, yarn construction, bindings, structure, and finishing techniques (e.g. steaming or washing) all inform the practitioner’s process and combine to create the behaviour and aesthetic expression of the resulting textile (Albers 1965; Piper and Townsend 2015; Tandler 2016). While most woven textiles are stable systems, which do not change significantly when removed from the loom, incorporating active yarns – high-twist, elastomeric, or other shrinking yarns – may produce a system with complex behaviour, where the yarns move through or distort the structure of the textile (Field 2008; Richards 2012). The research discussed in this paper used elastic and heat-shrinking yarns to explore the behaviour of such systems and their potential to create three-dimensional form in weaving. The active, shrinking properties of these materials, acting within the textile system, provided a means to investigate the notion of the workmanship of risk through emergent behaviour (Corning 2002), or, as Foote describes it, ‘the possibility of certain, repeatable processes leading to uncertain, non-repeatable outcomes’ (2017: 18). The industrial loom provides the repeatable process, while the textile system itself, its behaviour as interaction of material, structure, and finishing, offers an uncertain outcome.

Using a practice-based research methodology (Thomsen and Tamle 2009; Redström 2011) the research described in this paper seeks to bring a new understanding of the process of making, and to demonstrate the potential for industrial looms as craft tools when prioritising the workmanship of risk. It is true, however, that knowledge and understanding – of materials, structures, and bindings – built partly through experience of hand weaving, forms an important part of the research. The point of departure for this paper is the premise that, given such expertise, the industrial loom is sufficient for craft based on the workmanship of risk, and that pre-work and experimentation on handlooms is not always necessary. The experimental textiles presented here are used to analyse the process of form-making, and to propose the concept of emergent behaviour as a forming strategy in crafting.

Crafting self-forming textiles

The textile artefacts discussed in this paper represent a selection of four experiments conducted during the author's MA studies in textile design (2016-2018), as part of the research program *Re-forming weaving*. This research program aimed to explore methods for crafting three-dimensional textiles by exploiting active material behaviour, and the potential for forming diverse shape morphologies that could emerge from this process.

The experiments presented below are:

1. *Escaping wefts*, which aimed to explore the behaviour of monofilament when combined with shrinking yarn
2. *Shifting scales*, which aimed to examine the effects of scale on 3D form morphology
3. *Fluid surfaces*, which aimed to test 3D form at maximum shrinkage and the effects of transparency
4. *Transforming patterns*, which aimed to investigate the effect of warp:weft ratios, scale, and layer intersection on pattern and 3D form

At the beginning of the research program, before any jacquard weaving began, eight small samples were woven on a 24-shaft computer-controlled ARM handloom, testing different potential shrinking yarns in combination with copper wire as the resisting yarn. However, these samples highlighted the drawbacks of a shaft loom compared to a jacquard when weaving two-layer structures. Using a shaft loom limits bindings to simple patterns, repeated across the entire width, or confined to rectangles defined by vertical and horizontal lines: no diagonals or curves possible (Bang et al., 2016). Additionally, inconsistencies in the tension of the elastomeric wefts in the handwoven samples suggested industrial loom weft yarn handling would be beneficial, with the yarn fed directly from cone or spool, providing consistent yet adjustable tension.

Thereafter, all experiments were woven on an industrial jacquard loom with four repeats of 1320 warp ends. The warp was white cotton, 33 ends per cm – a width of 40cm per repeat, and total fabric width of 160cm. As the aim was to explore three-dimensional form, designs used simple geometric shapes – rectangles, hexagons, and circles. Form was generated through combining wefts with contrasting properties: elastic or polyester heat-shrinking yarns which had demonstrated the most shrinkage in the handwoven tests; and stiff monofilament yarns which resisted shrinkage to create the most volume. Some experiments incorporated lightweight inactive yarns (primarily cotton, but also lurex and polyamide) to add colour and textured surfaces, or break up monochromatic planes. The inactive yarns were selected to as they provided bright colour without impacting the interaction between stiff and shrinking yarns, while emphasising the distortions and movement of the rectangular plane of the textile.

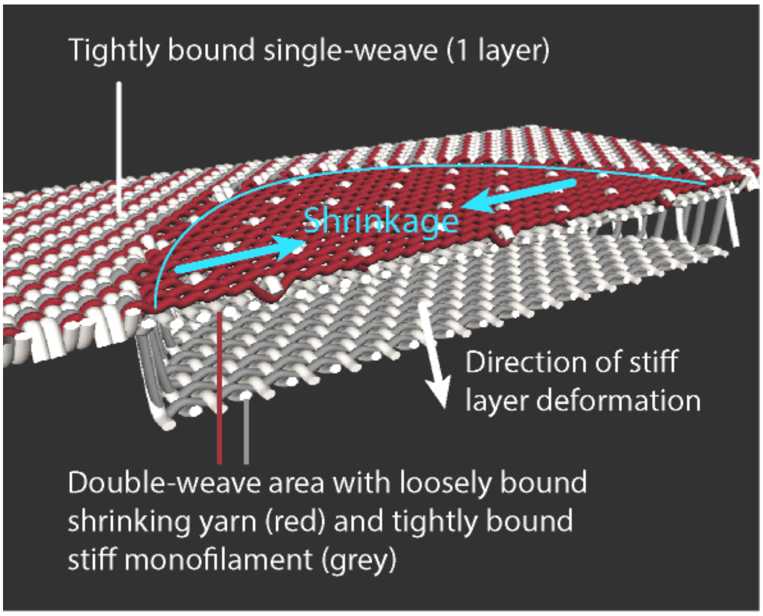

Figure 1: Diagram showing typical layer structure and relationship between bindings and layer behaviour. (c) Kathryn Walters.

Weave bindings were used to control yarn behaviour: tightly woven plain- or basket-weave were used to lock the weft yarns in place, while satins allowed them to shrink or move. The macro structure included double-weave areas, where the shrinking yarn in one layer could act to deform the resisting yarn in the other. These were surrounded by areas of single-weave which formed a boundary and restricted shrinkage (Figure 1).

The experiments explored the effects of different bindings, weft combinations, shapes, and scale on the woven textiles. The results illustrate the potential of industrial looms as tools for crafting complex textile systems and expressions, and the unexplored possibilities for designing emergent textile behaviours in weaving, in situations where unexpected outcomes are possible.

Escaping wefts: Crafting emergent behaviour in a complex system

Strikingly different effects from small changes in treatment are known as emergent behaviour and are characteristic of a complex system (Corning 2002). Such behaviour epitomises the workmanship of risk: The workmanship of certainty, by definition, must produce stable objects, whose behaviour is well-understood and planned for (Foote 2017; Pye [1968] 2010).

Experiment 1 (Figure 2) aimed to explore how the stiff yarn (polyester monofilament) would react when compressed by the shrinking yarn (polyester heat-shrinking yarn) and how this would translate into three-dimensional form. The textile had a two-layer structure containing shrinking yarn in the back layer, and monofilament and shrinking yarns together in the front layer. The textile had four rows (labelled A-D) which differed in the front layer only, containing different bindings and proportions of shrinking/monofilament yarns. The areas with one layer at the edge of each repeat separated the textile into four identical columns (labelled 1-4). An iron was used to steam the textile (activating the heat-shrinking yarn). The steam was directed to each column individually, and each column was steamed starting from a different point: from back or front, outside-in or centre-out.

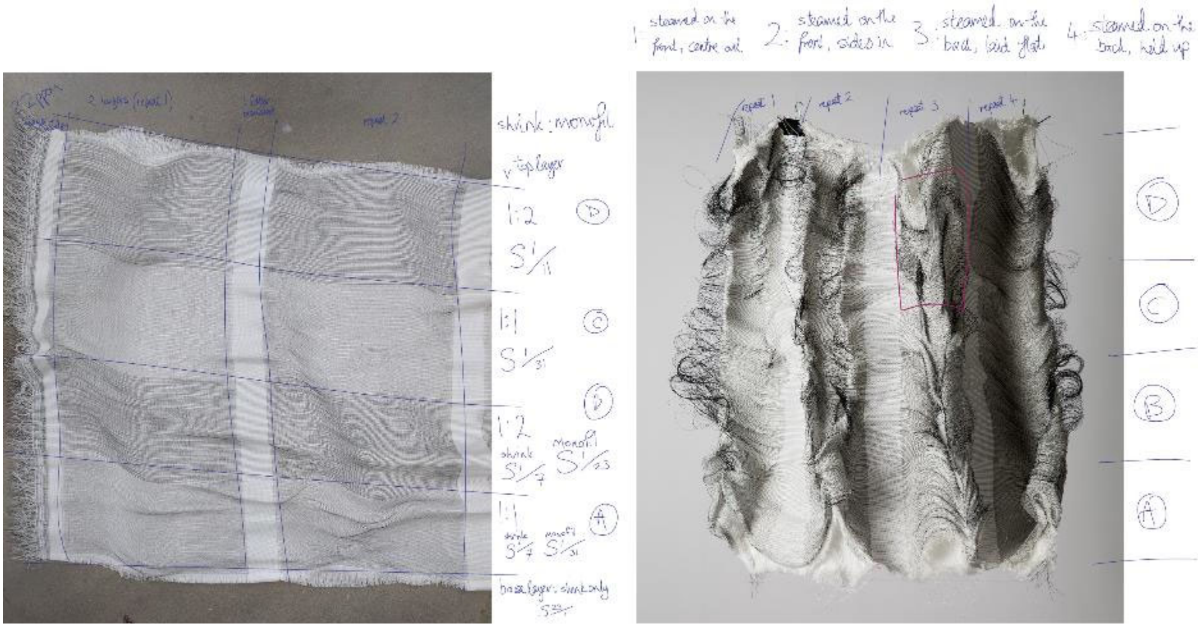

Figure 2: Kathryn Walters (2017). Escaping Wefts: Woven textile in black polyester monofilament and white polyester heat-shrinking yarn. Before (left) and after (right) steaming to activate the heat-shrinking yarn. (c) Kathryn Walters.

The result is a sample strongly demonstrating emergent behaviour, with the relatively minor alterations in either weave binding or steaming direction causing significant changes in appearance and form in each section. The monofilament behaviour was enabled by the industrial weft system, pulling yarn directly from the spool, and so avoiding the distortion of stiff yarns caused by winding them onto bobbins for a shuttle, as required for a handloom. The sample has a primarily chaotic aesthetic, or in Pye's terms 'free', with the monofilament weft escaping the bindings in areas, and freely forming loops. In other areas (such as the one marked in red in Figure 1), the monofilament was contained, 'regulated', forced into smooth waves, pulling the textile surface upwards.

Shifting scales: Challenging the limits of the loom for craft

Experiment 2 aimed to explore the effect of pattern scale on the three-dimensional form of the textile, and how this form would distort the basic rectangle. A motif of tiled hexagons was chosen because they combine simple tiling with diagonal and horizontal edges in a shape that could be easily resized (see Figure 4). The motif was woven in three sizes in a two-layer structure with monofilament in plain weave in one layer and elastic in a loose satin binding in the other (Figure 3).

Figure 3: Kathryn Walters (2017). Shifting Scales: Woven textiles in elastic (red and black) and polyester monofilament (transparent), in three sizes of a hexagonal motif (photographed sideways – weft vertical). (c) Kathryn Walters.

The results of experiment 2 demonstrate strikingly different forms. The large hexagonal motif produced a corrugated effect on the front, while appearing almost flat on the back. The small motif produced a smocking effect visible on both sides, caused by distortions in the single-layer areas of the textile. Perhaps predictably, the medium-sized motif had an effect somewhat in the middle, with deep cavities of distortion in the one layer areas, and large pockets of volume in the two layer areas, effects magnified by swapping the layer order on selected hexagons within the artwork.

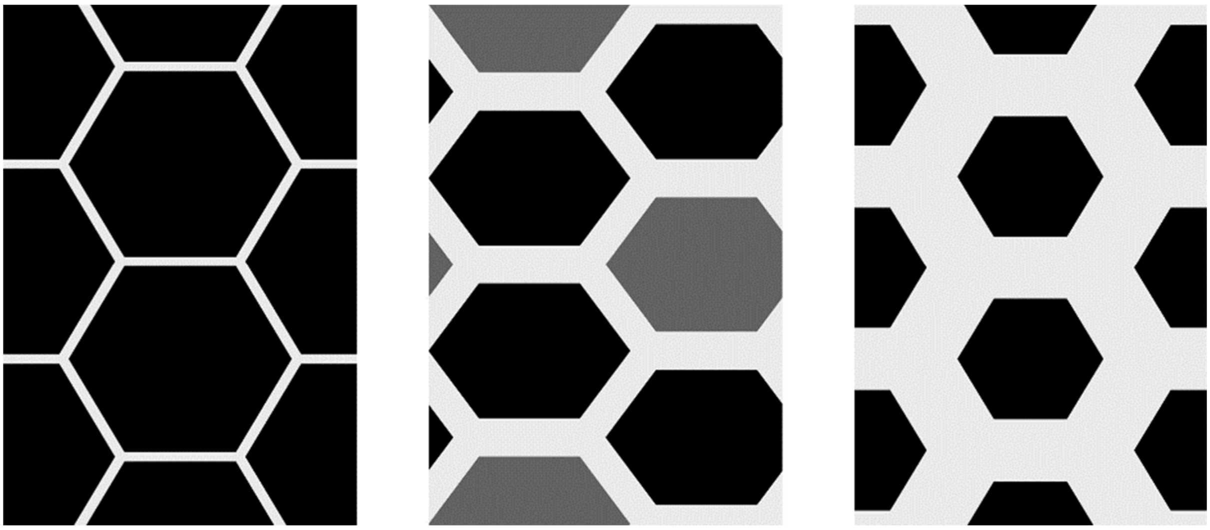

Figure 4: Kathryn Walters (2017). Artwork diagrams showing the relative scale of the hexagonal double-weave pockets (black and dark grey) and relationship to the single-weave surrounding areas (light grey). (c) Kathryn Walters.

A fourth design was attempted, incorporating multiple scales of the motif, and including a plastic tape yarn (Figure 5). However, it could not be woven, as the plastic tape built up at the selvedge, catching on the weft-feeding mechanism. This limitation is unique to the shuttle-less industrial loom: a combination of the cut selvedge structure, the high density required by the double-weave structure, and the stiffness of the plastic tape yarn. Thus the design could potentially be woven on a jacquard handloom such as the TC2 (https://www.tronrud.no/en/industrialized-products/products/tc2-loom). However, in that case, the use of shuttles for weft insertion may pose difficulties in regulating elastic weft tension or cause twisting in the plastic tape yarn.

Figure 5: Kathryn Walters (2017). Introducing complexity and finding the limits of the loom. Attempted textile in polyester monofilament (transparent), elastic (red), and plastic tape yarn (blue). (c) Kathryn Walters.

All tools have limits, as do materials and techniques. A skilled craftsperson, well-versed in the workmanship of risk, understands where these limits lie, but may also challenge them, building their understanding of 'the interdependent relationship of materials, tools and techniques in the making process' (Loh, Burry, and Wagenfield 2016: 190). Part of the workmanship of risk involves finding such limits, where a planned design is unable to be completed, and adapting tool, material, or technique to find a new solution. It points to the limits of the CAD process: a weave design may be devised and programmed in the finest detail, but this is no guarantee of its success on the loom. Only through attempting to realise a design can the limits of the system be found.

Fluid surfaces: Crafting with error as opportunity for design

An error may be perceived as a failure, or an opportunity. Embracing these as opportunities requires an open-minded focus 'on processes of transformation rather than outcomes' (Piñeyro 2019: 1880). To accept the possibility of error, and to see it as opportunity, is to fully embrace the workmanship of risk.

Experiment 3 was designed with a simple woven rectangle of heat-shrinking yarn in one layer, monofilament in the other, and lurex floating between the layers. It was intended to explore the effect on three-dimensional effect of shrinking across a full loom width, and to test whether the coloured lurex would be visible through the transparent monofilament layer. An error occurred during programming, with the weft selectors allocated incorrectly, so the weft yarns wove in the wrong layers (Figure 6). The error was not noticed until the sample was removed from the loom, as the heat-shrinking yarn appeared to be weaving correctly, and it was assumed it had been in the layer programmed to weave on top.

If the piece had been woven on a hand loom, the error could not have occurred, as it would have been clear which weft should be used for each layer based on the pattern of lifted shafts. This demonstrates the way in which the workmanship of risk is pushed into the design stage when working with an industrial loom. Decisions made in CAD must be trusted and relied on, embodying the textile as potential before it becomes physical reality.

Figure 6, left: Kathryn Walters (2017). Experimental textile woven with wefts accidentally transposed. Cotton, lurex, polyester heat-shrinking yarn, polyester monofilament. Right: diagram showing intended and actual layer arrangement. (c) Kathryn Walters.

A corrected version was woven, however when the results were compared, the 'incorrect' version displayed more interesting behaviour: as the largely unbound monofilament in the middle layer gathered at the bottom, it was free to move as the textile was handled, generating non-intuitive shifts in weight and form. This led to additional experiments, which further explored this behaviour, form, and movement (Figure 7). Without the mistake in programming, it is unlikely that this fruitful path of experimentation would have been discovered.

Figure 7: Kathryn Walters. (2017). Fluid surfaces: Woven textiles in cotton, lurex, polyester monofilament, and polyester heat-shrinking yarn, exploring form and movement. (c) Kathryn Walters.

The new weaves retained the loose satin binding for the coloured top layer – adding extra colour in stripes – resulting in loosely bound, shifting surfaces that slithered with movement.

The basketweave bottom layer in heat-shrinking yarn was likewise kept the same, with the textiles shrinking to approximately 30% of their original width once steamed. The changes between the pieces were to the binding of the monofilament in the middle layer. Figure 8 shows the relationship between the bindings used for this middle layer:

- plain weave, which locked the monofilament in place, providing the most structure and volume
- a loose rib weave, which allowed the monofilament some movement, reducing the volume
- floating loose without interlacement, enabling the monofilament to move freely, coiling within the textile – providing no support to the upper layer, but enhancing haptic sensation when handling the textile

The textiles from experiment 3 (Figures 6 and 7) reveal significant variations in form and movement through changes made only to the binding of the monofilament in the middle layer of each piece. Their distinctive forms and haptic behaviour are a further example of emergent behaviour in complex textile systems.

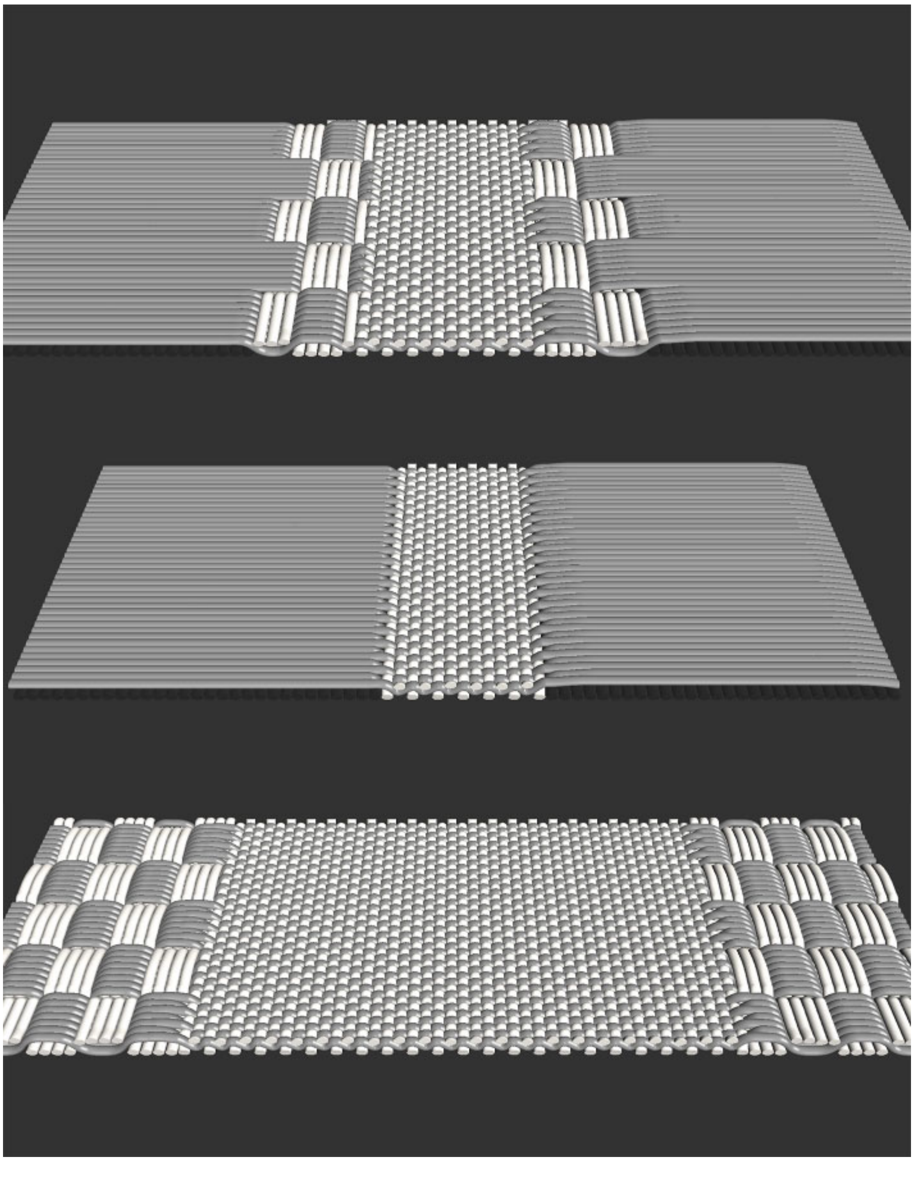

Figure 8: Kathryn Walters (2017). Diagram for each of the 3 textiles in Figure 7 that shows the relationship between the different bindings used for the monofilament middle layer, which determines the form once shrunk . (c) Kathryn Walters.

Transforming patterns: Enabling complexity in surface and textural expression in craft

Experiment 4 aimed to explore the effects of different ratios of warp and weft, scale, and layer transposition on the surface patterning and the three-dimensional form of a single textile (Figure 9). It showcases the potential of the digital design process combined with the industrial jacquard loom when crafting to prioritise the workmanship of risk.

The weave bindings mixed 8-shaft satin, plain weave, and a twill-type pattern (seen in the foreground in Figure 9, right), with one-layer areas at the top and bottom of the textile. Textural variations affecting the appearance of the patterning and the three-dimensional form were created by varying the proportions of warp and weft between the front and back layers in certain areas. The CAD process enabled these disparate bindings to be programmed individually, then combined: while the design had to be planned as a whole, considering in general the path of warp and weft, the detail of pattern in layers could be broken down to individual bindings.

Figure 9: Kathryn Walters (2017) Transforming patterns: Woven textile in elastic (white), polyamide monofilament (translucent), cotton (blue-grey), and polyamide yarn (blue), exploring warp and weft ratios, scale, and layer transposition. (c) Kathryn Walters.

The result is a textile with surfaces which both undulate smoothly, and buckle. In some areas, the weft strains to cover the warp, while in others it escapes completely, turning in loops and spirals before re-entering the woven structure. The combination of these areas of 'free' appearance, against others neatly 'regulated' in pattern, is an expression due entirely to the behaviour of the textile as a complex system: the textile making itself.

Findings

The textile artefacts in this paper express a range of shape morphologies emerging from loom-woven complex textile systems. Table 1 summarises the experiments, their intended aims, and unexpected findings resulting from crafting prioritising the workmanship of risk.

Table 1: Summary of experiments.

Experiment	**Aim: To explore/understand**	**Unexpected finding**
1. *Escaping wefts*	Behaviour of monofilament when combined with shrinking yarn	Emergent behaviour due to steaming direction
2. *Shifting scales*	Effects of scale on 3D form morphology	Limitations of industrial loom in relation to materials and structure
3. *Fluid surfaces*	3D form at maximum shrinkage and effects of transparency	Error producing unusual haptic expression leading to structures developing understanding of relationship between form and construction
4. *Transforming patterns*	The effect of warp:weft ratios, scale, and layer intersection on pattern and 3D form	Combination of free and regulated expression

The textiles are the outcome of a method of crafting that blends the workmanship of risk, enabled by experiential knowledge (developed through handcraft) and active materials, with CAD/CAM, in the form of digital design and industrial jacquard weaving (Figure 10). This method bridges divisions between the physical and the digital, hand and machine, certainty and risk. Experiential knowledge informs digital design, bridging the gap to physical outcome, while leaving space for unexpected outcomes and the potential for emergent behaviour. The textile is woven by machine, but material choices are informed by the sensitivity of the hand, where tacit knowledge is embodied: the way in which a yarn's physical properties transform into the tactility of the textile. Risk is explored as designs push the limits of certainty into the unknown and the new.

Finally, a new language of forming in weaving – escaping wefts, shifting scales, fluid surfaces, and transforming patterns – describes the expression of these textiles with their complex three-dimensional surfaces and forms.

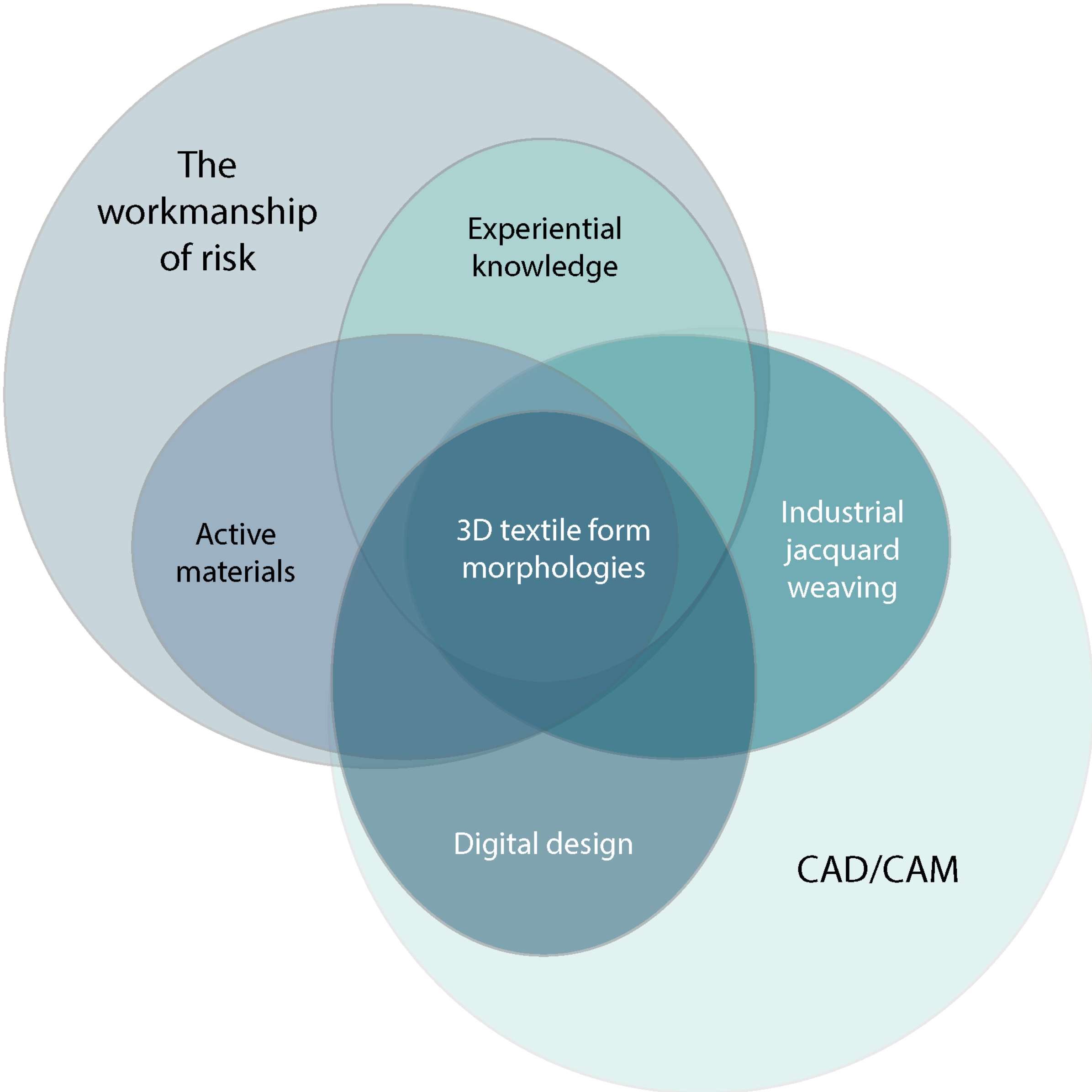

Figure 10: Kathryn Walters (2020). Elements of crafting at the intersection of the workmanship of risk and CAD/CAM. (c) Kathryn Walters.

Discussion

Loh, Burry, and Wagenfield state that: 'The conflict in making with [CAM] tools is that almost all outcomes are predefined digitally and therefore inherently of low risk. However, there remains a degree of uncertainty in the making process, depending on the use of material and techniques' (2016: 189). They define three areas of craft practice within which this uncertainty, or risk, may reside: materials, tools, and techniques. Mass manufacturing, or production in the workmanship of certainty, seeks to remove risk from all three areas. In contrast, craft practice may act to reduce risk in one or more areas but does not completely eliminate it.

In the experimental woven textiles presented in this paper, risk resides primarily in the materials: changing the materials fundamentally changed the form and form-making behaviour of the textiles, while changing tools, for instance to a jacquard hand-loom, would have significantly less impact. Yet, as the examples in this paper demonstrate, risk is far from eliminated from the tool (Shifting Scales) or technique (Fluid Surfaces), even while working with CAD/CAM tools and processes.

This is not to propose that CAM tools replace handcrafting, in weaving or any other craft. As Pye ([1968] 2010) points out, very few handcrafts are unmediated by tools. Crafting 'by hand', as in hand-loom weaving, offers tactile exposure to materials and structures. This embodied experience enables tools and materials to talk back to the crafter, building tacit understanding. Thus, digital and analogue tools may sit alongside each other in craft practice. Experience with one informs the use of the other, broadening the crafter's repertoire. Piper's 'Transitional design methodology' (2018: 92-93) provides one model. This paper argues for the inclusion of digital tools alongside analogue 'handcraft', but also a dissolving of the boundaries between digital and analogue in craft practice.

When the predominance of risk lies in the materials, or, more accurately, in the combination of materials and structures that make up the craft object (in this case, the woven textile system), emergent behaviour may be introduced. Emergent behaviour becomes a factor in shaping the object when small variations in the making process produce significant changes in the object's form. When working with active yarns, emergent behaviour is a potential outcome. This is most clearly seen in Escaping Wefts (Figure 1).

Emergent behaviour presents a crafting strategy that is not limited to weaving with active yarns. Falin et al. (2021) discuss 3D printing with clay, with a focus on the interaction between crafter and the material, mediated via the tool. They demonstrate that through interaction with the printer variables and material flow during the printing process, a simple digital design may be used to craft multiple unique objects. The impossibility of exactly repeating the same form relates to what the authors describe as the improvisational and irreversible nature of the process, which 'shows how easily small differences in the tools have an impact on the outcomes of the work' (Falin et al. 2021: 9). In this case, the emergent behaviour arises from the interaction of the material and the tool, and the maker and the tool, 'a constant transition between hands-on and digital experiences of making' (Falin et al. 2021: 6).

Ingold (2010) describes crafting as a process of following the flow of material, Risatti (2007) as a process of transforming material. Emergent behaviour as a crafting strategy requires bringing the material to a point of instability, a tipping point, where it has the potential to form in multiple ways. Then we must let it resolve itself, as it interacts with the tools and techniques we use to form with. In this way, even if we repeated the crafting sequence over and over again, each time the material would form a little differently, creating a new object. This process becomes a way of taking 'into account the fine surprises of a material' (Albers 1946: 31): by following its flow.

While digital crafting or working with CAD/CAM systems has become more accepted as craft practice, working with emergent behaviour is a strategy for craft that reintroduces risk and uncertainty into making processes intended for the workmanship of certainty. However, this strategy is not necessarily limited to digital crafting, and could be employed in manual and analogue craft practices, wherever uncertainty and serendipity lie with manipulation of the material. The experimental textiles presented in this paper have been crafted through a process embracing the workmanship of risk, one that allows space for emergent behaviour to arise through the materials and the textile as a system.

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Contributor details

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List of illustrations

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Figure 10: Kathryn Walters. (2020). Elements of crafting at the intersection of the workmanship of risk and CAD/CAM. (c) Kathryn Walters.