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FIBRE, FABRIC, AND FORM: EMBEDDING TRANSFORMATIVE THREE-DIMENSIONALITY IN WEAVING

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ABSTRACT

Textiles, and textile objects, no matter their scale, retain traces within their expression of the fine-scale fibre or yarn from which they are formed. Woven textile forms are typically constructed using hierarchical cut-and-assemble techniques, where the expression at the fibre-scale may be subsumed by that of the dominant form expression. Through experimental design research, a framework for designing non-hierarchical woven textiles has been developed, which navigates between 2D and 3D thinking and micro- and macro-scale design elements. This framework is contextualised through three methods for embedding three-dimensional form in a textile as it is woven: Catenary Structure, Tension Folds, and Expanding Layers. An example is presented for each method, and the design of these multimorphic textile-forms is discussed, alongside the variable nature of scale in the digital textile design process. The framework exposes the multimorphic nature of woven textile-forms, and provides a lens for understanding their design process.

INTRODUCTION

Woven textiles can be viewed through different scales: the micro-scale of fibre, yarn, and structure, and the macro-scales of fabric and form (Castán Cabrero, 2019, p.17; McQuillan, 2020, p.354). The micro-scale is that at which weave bindings are designed: the intricate interlacement of warp and weft. Textile design also occurs at the scale of the fabric, where patterning and texture emerge. This fabric scale is inextricably tied to the method of production, and so it is also the scale of the loom.

TEXTILE FORM ...

Textiles are both objects of design, and material for design. As material for design – fabrics – they are treated as formless materials: "filler[s] of form" (Oxman, 2010, p.78). This hierarchical design process – the "formal approach" (Heimdal et al., 2012, p.1) – treats form and material as two distinct entities (Landahl, 2015, p.9), in which textile design and object design occur sequentially. In the formal approach, the structure or form is designed before "defining materials requirements" (van Bezooyen, 2014, p.282) in which an existing textile is selected. The fabric is transformed through cut and assembly methods, integrated as form into the structure of the new design. Its materiality – the form and structure of the textile as object of design – is subordinated to its role as 'skin' (Nilsson, 2015). Thus the formal, hierarchical approach produces a façade, and in doing so conceals its structure (Semper, 1989, cited in Jeffries and Conroy, 2006, p.235).

However, a non-hierarchical approach – "formgiving" (Heimdal et al., 2012, p.1) – provides an alternative. Writing on the relationship between form and function in architecture, Behne describes a progression from façade to "shaped space" and "designed reality" (1923/1926, cited in Smith, 2014, p.57). He writes of a building, that it "was an indivisible, unbroken whole… The building was itself form, it needed no forms" (p.59). With similar effect, textile design may produce three-dimensional form through a non-hierarchical process. In this process, material and form are produced simultaneously (Landahl, 2015), creating a 'textile-form' (McQuillan, 2020, p.19). This is common in

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knitwear, through whole-garment and fully-fashioned knitting. Underwood (2009) and Kalyanji (2020) have researched a wide range of knitted non-garment three-dimensional morphologies.

Harvey et al. (2019) describe the design and production process for weaving textile-forms on a specialised 3D loom. Their 'library of tendencies' is analogous to Underwood and Kalyanji's morphology research, demonstrating basic possible behaviours or forms through this technique. Such 3D looms are set-up specifically for production of multilayer structures, and shuttle weft insertion enables partial row weaving. These looms are, however, rare, limited to narrow weaving widths, and the design process is complex.

Research in weaving textile-forms on conventional (2D) looms has primarily been carried out in textile technology and engineering, and is focused on preforms for composite manufacturing (e.g. Mountasir et al., 2015; Geerinck et al., 2019). These take the form of geometrically-shaped hollow spaces running in either weft or warp direction throughout the textile, producing deep honeycomb or grid structures.

This geometry, characterised by architectonic morphologies based on the rectilinear logic of warp and weft (Smith, 2011), also occurs in non-garment textile-forms in art and design, as in Lucy McMullen's Maelstrom (in Hemmings, 2012). Whole-garment weaving approaches such as those of Issey Miyake and Dai Fujiwara's A-POC Queen Textile (1997) and Jacqueline Leffert's Gestalt Process (2016) break away from the grid of the loom, and create simple two-layer pockets, relying on the enclosed body to provide form to the textile. However, methods for generating more organic morphologies in three-dimensional loom-woven textile-forms is under-researched.

... AND SCALE

In hierarchical design processes, the scale of the form may be vastly different from that of fabric or fibre (Heimdal et al., 2012). From tiny doll clothes to huge architectural and geo-textile applications, textile objects encompass a wide range of sizes and scales. Through the hierarchical design process, which transforms the materiality of textiles into façade, the scales of fibre and fabric are subsumed in the dominance of form. But in non-hierarchical textile-forms, as fibre interlaces to build fabric, it simultaneously creates form. Thus, the scales of fibre, fabric, and form are linked.

This intertwinement of scales requires multimorphic thinking during the design of woven textile-forms. Multimorphic objects can be "read and understood at many scales, axis [sic], and dimensions simultaneously" (McQuillan, 2020, p.352). During the design process, weave structures must be developed that enable the unfolding and transformation of the textile from 2D to 3D. Flat artwork files encode multiple layers in the textile-to-be, while digital design tools dissolve senses of scale and materiality (Oxman, 2010). During the design process, a textile-form occupies the scales of fibre, fabric, and form, all at once. Thus there is a need for methods in textile design that consider and unify the disparate scales.

Through experimental design research, a framework has been developed for woven textile-form design which integrates the micro- to macro-scale elements in the design process. To contextualise this framework, this paper presents and discusses three examples, each representing a different method for producing three-dimensional woven textile-forms. They embody multimorphic thinking, demonstrating the relationship between fibre, fabric, and form. Their transformations from 2D to 3D reveal time as a critical element in textile-form design.

RESEARCH PROGRAMS AND EXPERIMENTAL WEAVING

Binder and Redström describe a research program as a "provisional knowledge regime… a hypothetical worldview" (2006, p.4) against which the results of research are assessed. As Redström (2011) describes, the design research program and its experiments evolve together, influencing, challenging and transforming each other. Thus theory and knowledge in experimental design research are derived through the interaction between the experiments and a design research program. Theory is brought in to the research program to contextualise the experiments, and findings are expressed through experimental examples, or exemplars (Bang and Eriksen, 2014; Krogh et al., 2015). The framework and three methods presented in this paper form a set of such exemplars.

The ongoing design research program which gave rise to the experiments seeks to develop new morphologies and behaviours in woven textile-forms. In this context, textiles are viewed as systems consisting of fibre/yarn material/s, properties relating to their construction (weave bindings, layer structures, density, etc.), and the effects of finishing techniques. The textile as system has behaviour and form that are the result of the combination and interaction of its component elements (Tandler, 2016).

The textile-form system requires a multimorphic design process, as changes to any one element has consequences for the whole system. This gestalt property (Rawlins, 1953, p.49) necessitates that the design process for woven textile-forms constantly shifts between 2D and 3D thinking, and between micro- and macro-scales. Figure 1 illustrates a framework for woven textile-form design.

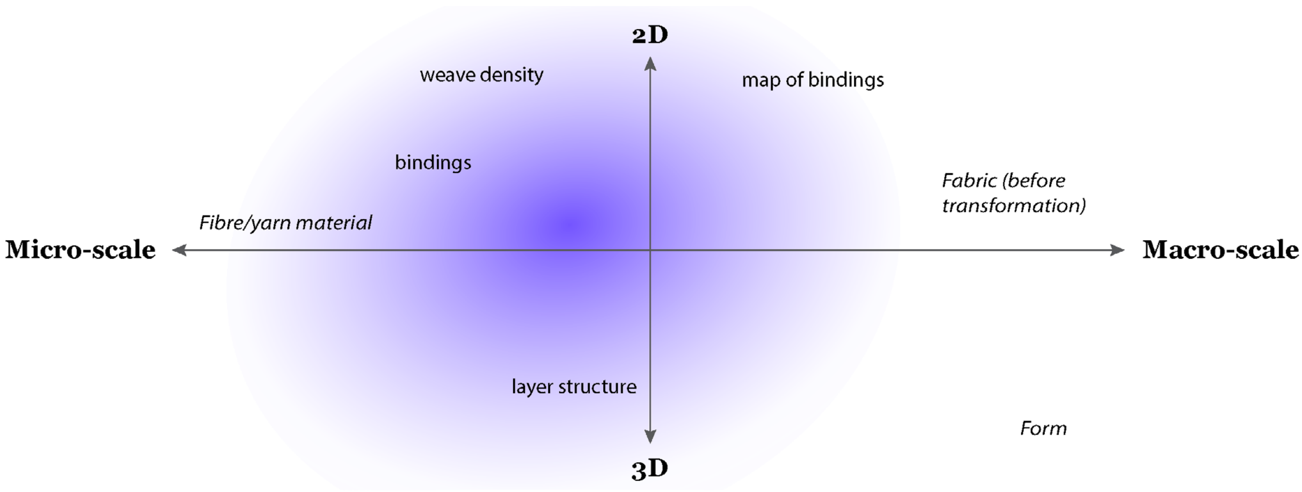

Figure 1: A framework for the design process for woven textile-forms. It shifts between elements at micro- and macro-scales, and between 2D and 3D thinking. There is no linear path between design elements, as changes to one have flow-on effects for the whole. This multimorphic design process is represented by the zone of colour, with its focus between layer structure and bindings, the elements manipulated during the digital design stage.

The research program is conducted through experimental weaving. This method uses CAD/CAM (computer-aided design/manufacturing) in the form of digital weaving software (ScotWeave) for programming, and computer-controlled jacquard power looms for the weaving of experiments.

Each experiment begins with an idea, perhaps about a combination of materials, or a particular structure. This is developed through quick sketches, diagrams, and notes. These provide the bulk of the information required to program the design in software. During the programming stage, these plans may be adjusted as the process reveals or suggests changes. Once a loom-ready file has been produced, a few notes on technical elements (weave density, weft selectors) are all that is required to produce the textile. Even during weaving, changes may be made, for example, density may be adjusted, or yarns exchanged, as the weaving process itself provides new information on the experiment while it develops.

DIGITAL DESIGN AND THE DISSOLUTION OF SCALE

CAD tools such as weaving software may offer shortcuts, technical assistance, and simulations, but they can also impose specific processes and procedures requiring certain ways of thinking (Dormer, 1997, p.146). As tools designed to aid hierarchical design processes, they act to dissolve senses of scale and materiality (Oxman, 2010). In weaving software, bindings are programmed in draft notation (Figure 2). Layers may be programmed separately, while the software does the work of integrating them. But the square grid, representing intersections between warp and weft, does so without consideration of material or scale. The relationship between draft and woven fabric – the textile system – is dematerialised. This dematerialisation is not unique to digital design, occurring when drafting by hand as well. But design processes involving direct interaction with the material, such as yarn wrapping and sampling, remain distanced from digital design, separated by the barrier of the screen.

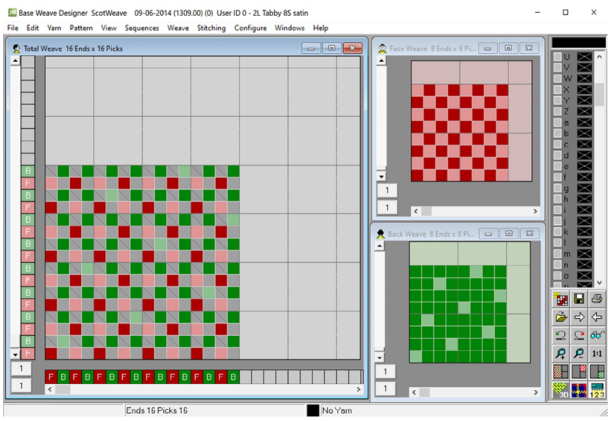

Figure 2: Screenshot from ScotWeave jacquard base weave module showing the design screen for double-weave binding, with face and back layers designed separately.

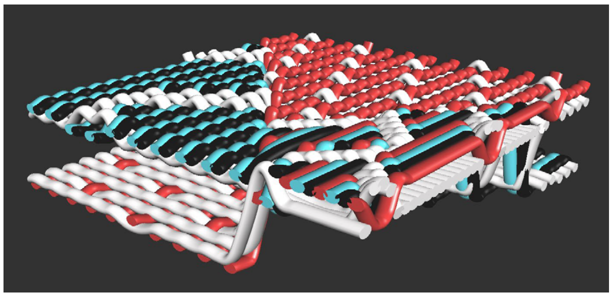

Figure 3: Screenshot from ScotWeave jacquard design module showing a 3D yarn path simulation in a jacquard design in a section with weave transition from single- to double-layer.

The software compiles the bindings into a design file when combined with the weave artwork or "map of bindings" (McQuillan, 2020) – a 2D plan in which each colour indicates a different weave structure. ScotWeave offers a 3D view at this stage, in which small sections of the design may be viewed as yarn interlacements (Figure 3). This view enables confirmation of structure and yarn sequence. However, these 'yarns' are plastic, interlacing and separating perfectly. Once again, the materiality of the textile is absent. Furthermore, the lack of reference dissolves all sense of scale. When enlarged on the monitor, it can be easy to forget that a section being viewed may occupy less than a centimetre once woven. Meanwhile the plasticity of the simulation distorts and misrepresents the relationship between layers.

CAD software may enable complexity in design, but in doing so it strips away the materiality and scale that actually make up the textile. The complex behaviour that enables transformativity in flat-woven textile-forms cannot be reproduced in these hierarchical design environments. Instead, they must be made tangible in their specific materials and scales, embodied through weaving.

RESULTS: 3 METHODS FOR WOVEN TEXTILE-FORM DESIGN

CATENARY STRUCTURE

This first example, shown in Figure 5, was developed as part of a series of experiments combining paper-tape yarn with wool yarn, to explore the effect of fibre and finishing on textile behaviour and form. It was designed as a two-layer pocket, closed on all sides by a single-layer binding. The bottom layer was woven with a wool yarn weft, in a loose satin binding. The top layer was woven with linen and paper-tape yarn wefts, in a circular pattern of satin bindings from loose in the centre to tighter near the edges. It was woven on a jacquard loom with a cotton warp and four 40cm repeats across the loom width. The repeats were separated into four samples in order to test different treatments. One sample was put through a 95°C machine wash cycle, and left to dry hanging upside down, fixed to a board by the four corners. Figure 5 shows the design elements of this example mapped against the framework presented above.

This form-making method works by creating a surface that is first pliable and shaped by hanging, then hardens to support the form. In this example, the felting caused by the washing process shapes both layers differently due to their different fibres and fabric structures. The interaction between the reshaped layers affects the specific three-dimensional form at the small-scale, meeting and combining with the gravity-induced arch at the large-scale.

There is a continuity between the micro- and macro-scales in the way they both build and express the form. While the potential for form is encoded in the micro-scale of fibre, yarn, and structure as it is woven into the macro-scale of fabric, this form is only latent until the fabric is finished through the washing and drying process. As it is the interaction at fibre and fabric scales that enable the three-dimensional form, the form retains traces of both scales in its expression (Figure 4).

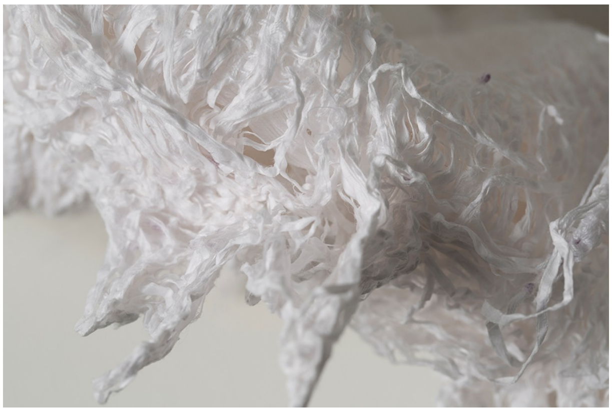

Figure 4: Form and expression at the micro-scale of the fibre.

This expression reveals the relationship between the scales of fibre, fabric, and form. While the wool felted evenly across the width of the two-layer area, the paper yarn only partly felted, and pulled out of the binding in areas with looser interlacement. These traces expose the construction of the fabric, while the crumpled surface at the front of the form reveals its origin in the flatness of fabric. This intertwinement of scales is intrinsic to the woven textile-form, yet the digital design process deals only with the small-scale.

Thus the three-dimensional form is a result of the interaction of the fibre properties, the fabric (weave structures), and the two finishing processes. Interaction between these elements occurs at both fibre and fabric/form scales, such that changing any one element would result in a different form. The precise expression of the textile is an emergent property because of this interaction across scales. Repeating the same process with one of the other samples would likely have produced a similar three-dimensional shape, but the specific clumps and tufts of paper, texture, and fabric folds would have been quite different. It is an example of what Foote describes as "certain, repeatable processes leading to uncertain, non-repeatable outcomes" (2017, p.18).

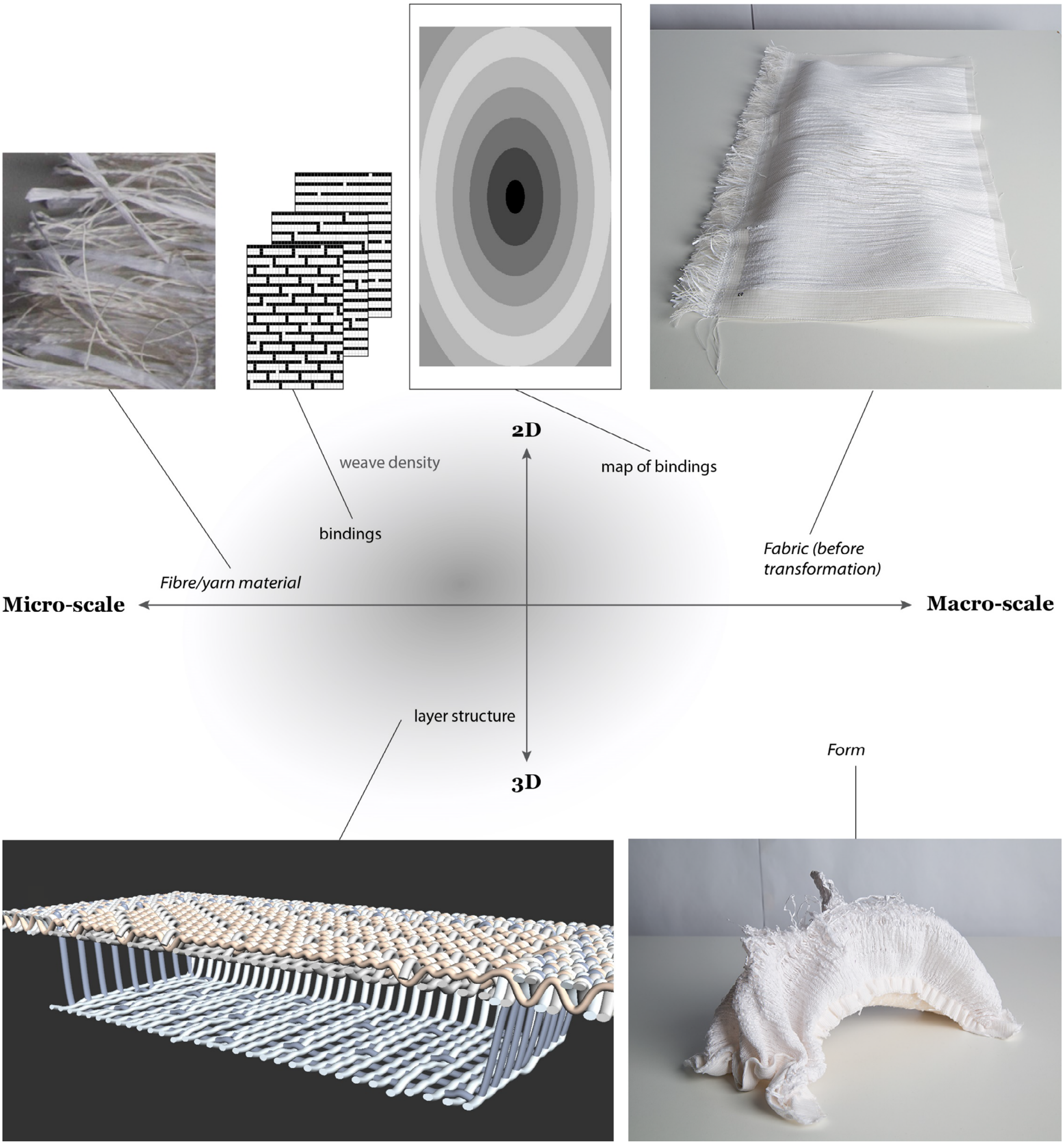

Figure 5: The design elements of the Catenary Structure mapped against the design framework.

TENSION FOLDS

The second example (Figure 6) resulted from a more developed set of experiments, exploring the potential for the paper yarn to support three-dimensional form without wet-finishing. It was designed as two-layer tubes, with crossed patterns of folds, separated by vertical bands of a single-layer binding. This piece was woven on the same cotton-warped loom, but the repeats were not separated. The bottom layer was woven in a loose compound satin, with elastic on the bottom and polyamide (blue) on the inside. The top layer was woven in compound bindings, with paper-tape yarn on the face and the same polyamide on the inside. Folds were created through paper yarn floats – on the outside for mountain folds, and on the inside for valley folds. The valley folds can be seen on the outside of the textile-form as blue lines. Figure 6 shows the design elements of this example mapped against the framework presented above.

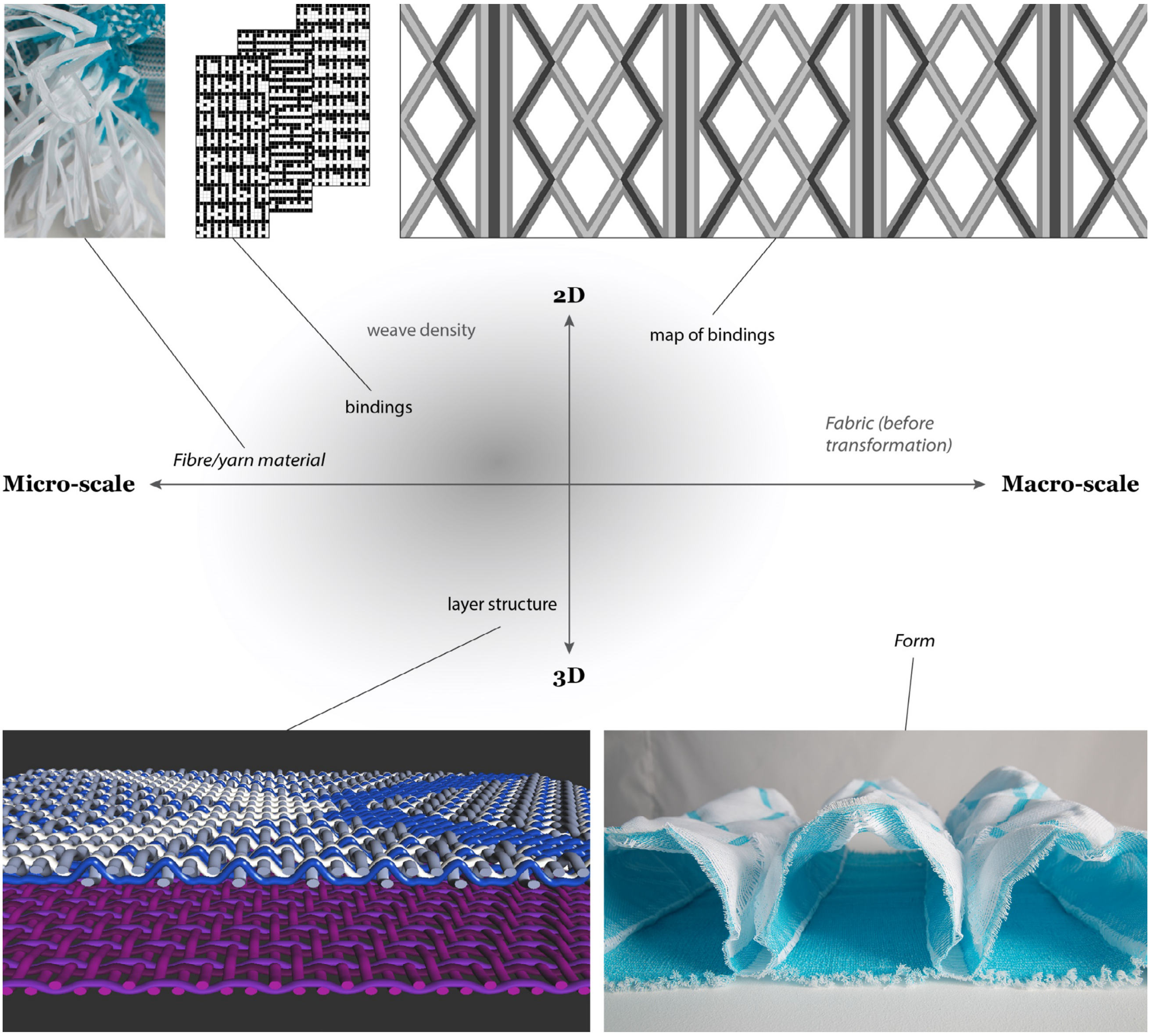

Figure 6: The design elements of the Tension Folds example mapped against the design framework. There is no 'fabric' element, as the elastic begins to shrink and the textile to form even while on the loom, as the tension holding it flat reduces.

This form-making method is reliant on the stiffness of the paper yarn folding under tension. The fold lines designed into the structure of the fabric guide the release of tension selectively, shaping the form. In this example, tension is provided by the elastic lower layer. The intersecting diamond fold structure provides self-reinforcing stability.

There is a sharp division between the way the micro- and macro-scale elements are expressed in this example. All the elements that build the form have been embedded at the fibre and structure micro-scale, at the design stage. The fabric and the form are constructed simultaneously, as the elastic begins to shrink even before the textile is removed from the loom (thus there is no 'fabric' element shown in Figure 6). This results in the subordination of the fibre-scale expression in the textile-form, which remains only as colour and texture in the macro-scale fabric.

Therefore there is a discontinuity of expression between fibre and fabric scales: The dominant expression is of the fabric and form. This expression is interrupted at the mountain folds, where the paper yarn breaks from the fabric surface. As the fold occurs at slightly different locations on each weft, a visual disjunction is created. This effect is dependent on the specific scale of the paper-tape yarn, which is significantly larger than the other yarns in the textile-form, making it closer in scale to the fabric surface it disrupts.

Similarly to the previous example, the transformation of this textile-form from 2D to 3D is the result of the interaction between elements at the scale of fibre and fabric. The use of elastic yarn removes the need for finishing as a transformative technique. While steaming encourages the elastic and polyamide yarns to shrink fully, the textile-form exhibits three-dimensionality as soon as it is cut from the loom.

EXPANDING LAYERS

In contrast to the previous two methods for creating three-dimensional form in woven textiles, the Expanding Layers method requires cutting the textile-form in order to release three-dimensionality through unfolding layers. This method is exemplified here by the Feldspar Dress (Figure 7), developed during a collaborative project with fashion design researchers Holly McQuillan and Karin Peterson (the project is described in full in McQuillan et al., 2021).

The Feldspar Dress was woven on a single-repeat jacquard loom with a fine polyester warp, and polyester and heat-activated shrinking yarn weft. It was designed as a single piece of woven fabric, with areas of two, three, and four layers. Some layers allowed it to be cut and separated into a front and two backs (separating as shown in the map of bindings in Figure 7). Other layers were cut to open up the 12 godet pleats in the skirt (see paper model in Figure 7).

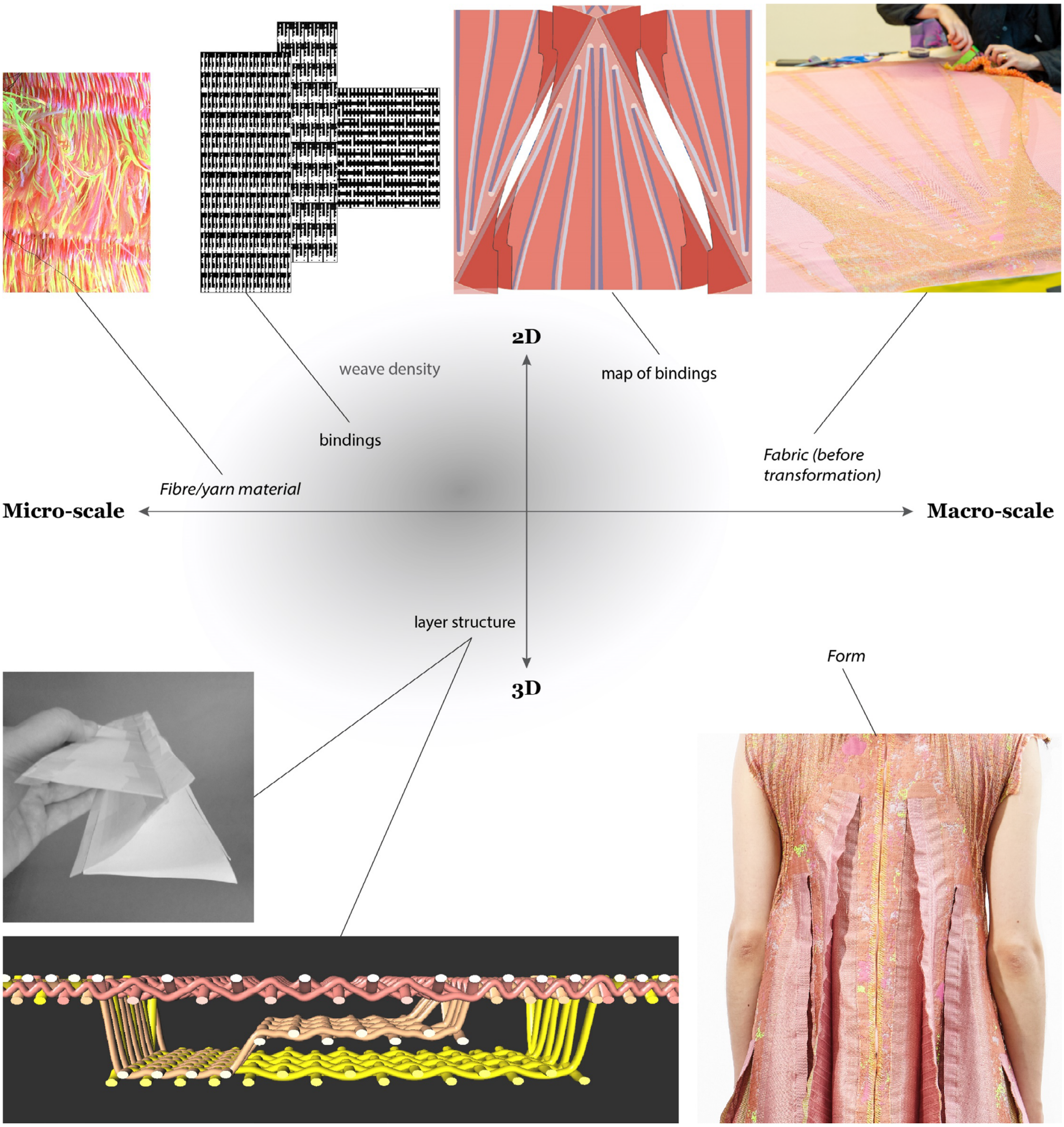

Figure 7: The design elements of the Feldspar Dress mapped against the design framework.

The previous form-making methods combined fibre and fabric scale effects. Conversely, the Feldspar Dress pleat structure works by opening up the fabric of the textile, enabling linked layers to expand. Here, the transformation is focused at the fabric scale, more like the hierarchically designed forms it is modelled on. Yet it is enabled by the weave structure – interlacement patterns at the yarn scale.

The transformation from fabric to form is activated through the act of cutting woven 'seams' to expand the layers and thereby release the form. Cutting creates vulnerability; it is "the very act which is potentially ruinous to the fabric" (Sutton and Sheehan, 1989, p.29). Thus it was critical that the seams, which join layers, and where cuts are made, were robust enough to minimise fraying, and stable enough to withstand the tension of layers being pulled in opposing directions. As a result, the pleat seams, where the layers join, were much stiffer, almost sharp, in comparison to the soft drape of the pleat fabric. This rigidity is a trace that reveals the interwoven relationship between fibre, fabric, and form. The multilayered fabric, built from intricately interlaced fibre, shapes the form, which retains imprints of its origins in the woven rectangle.

The inclusion of shrinking yarn along with the expanding layer structure enables both continuous and discontinuous expressions of scale in the Feldspar Dress. In the pleat seams, the expression is discontinuous, as the form derives from micro-scale effects, similarly to the Tension Folds example. Yet, in the bodice, where the shrinking yarn has been activated, the form is constructed from both micro- and macro-scales in the fibre, structure, and fabric. It is a more subtle effect than that seen in the Catenary Structure example. If the shrinking yarn in the skirt pleats were activated, the two expressions – continuous and discontinuous – would be juxtaposed.

FIBRE, FABRIC, FORM… AND TIME

Through experimental design research, a framework for non-hierarchical woven textile design has been developed. This new approach for weaving design is a nonlinear process which reflects the multimorphic thinking required when designing involves working between 2D and 3D and across micro- and macro-scales.

Additionally, three methods for producing three-dimensional woven textile-forms have been explored – Catenary Structure, Tension Folds, and Expanding Layers. These provide a context for the framework. The expression in each of these textile-forms emerges from the interaction of micro-scale elements – fibre, yarn, and structure – and macro-scale elements – fabric and form. The specific expression of each textile-form is either continuous or discontinuous across these scales. Where the form outcome is solely a result of design decisions at the micro-scale, these micro-scale elements are suppressed in the macro-scale expression. However, where a finishing process is used to develop form through manipulating the textile-form at the macro-scale of the fabric, the expression of the micro-scale elements is retained alongside the macro-scale elements in a continuous expression.

The experimental design research presented in this paper is carried out through a method that Heimdal et al. call "the formgiving approach" (2012, p.1) in which different ways of processing or treating a material is explored. However, here, the formgiving approach is applied not to individual materials, but to combinations of materials. The materials are 'processed' through weaving, where different structures and material combinations have been explored. These woven textiles have then been 'treated' through different finishing techniques where needed to activate the transformation from 2D to 3D.

Working digitally in CAD, scale is thought of primarily in terms of proportions – relationships between elements. The pattern in the artwork directly corresponds to the desired number of weave bindings, and bindings are judged by the length of yarn floats in the woven fabric. An estimated weft density is used to rescale (shorten or elongate) the artwork, which directly relates to the physical scale of the yarn and the bindings, but for now it is thought of solely as a number. This abstraction may be emphasised in early experiments, in which precision is considered less important.

Nevertheless, scale is implicit in weaving, even when disguised by the digital environment. The design is prepared for a specific loom, with the number of warp ends in the repeat converted to pixels, indicating an exact width. The weft density is directly related to weft yarn width, tightness of the bindings, and the warp density and weight. When weaving begins, this weft density number becomes embodied not only in the fabric, but also in the haptics of the loom. Is it too tight, or too loose? The answer is felt through the hand on the cloth, and the sound of the reed hitting the fell. It remains just a number, to be raised or lowered, or recorded for future reference as just right. But the decisions made in the scale-less digital environment are realised as fibre and yarn become fabric. Therefore, the framework functions to link the digital design process with the physical making process and its outcome.

A key difference between the Feldspar Dress and the earlier examples is that its form is very precisely designed. In contrast, the forms of the Catenary Structure and Tension Folds examples arose during the experimental design and making process. This has enabled unrepeatable – emergent – form-making behaviour. In the Catenary Structure example this behaviour is driven by the same mechanism as Frei

Otto's yarn-based "material machine" described by Spuybroek (2005, p.7). In the material machine wool threads in a geometric arrangement are loosened and felted, creating an "optimized path system" (p.10). In the shrinking structure textile-form, the geometric arrangement is the woven fabric, which already contains the necessary looseness as it is constructed. Instead of producing paths, the transformative felting process releases the three-dimensional form potential of the two-layer textile. Spuybroek goes on to state that "the geometry does not follow the event, geometry coevolves with materiality" (p.11) – qualities characteristic of non-hierarchical processes.

As experiments in formgiving, neither Catenary Structure nor Tension Folds have been considered in relation to an application. However, as they were woven on an industrial jacquard loom and transformed through common finishing treatments (machine washing and steaming respectively), both methods are open to industrial processing and product applications. With respect to Expanding Layers, McQuillan's (2020) research demonstrates the applicability of this method in fashion, and it could equally be applied in other fields such as furniture or product design. She also suggests the use of computer-controlled laser cutting to automate the transformation process.

Each example in this paper expresses the relationship between fibre, fabric, and form differently. While the fibre scale is an equal part of the expression of the Catenary Structure – a continuity of expression across multiple scales – fabric and form are dominant in Tension Folds – a discontinuity of expression. The Feldspar Dress contains both continuous and discontinuous expressions, due to its combination of form designed through micro-scale alone, and through micro- and macro-scale together.

A final scale that plays out in woven textile-form design is time. The transformation from 2D weave to 3D textile-form relies on changeability – embodied in fibre behaviour and fabric structure. Whether this occurs as the textile is removed from the loom, or requires intervention through finishing techniques, textile-forms are objects in time (McQuillan, 2020, p.354). The element of time is not identified in the framework; it remains implicit in the space between fabric and form.

These three methods for creating morphologies in three-dimensional loom-woven textile-forms demonstrate the potential of the framework as a new approach to weaving design, creating new expressions. Further research is planned to explore the Expanding Layers method in active yarns (those with shrinking and resisting behaviour), to explore how the fibre properties interact with the fabric and form expression. Future research could explore these micro- and macro-scale elements in relation to time, different scales of fabric and form, other fibre qualities, or alternative form-making methods. This is a field with a wide range of possibilities, of which the examples presented in this paper are only a few.

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