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Multimorphic Textiles: Prototyping sustainability and circular systems

Holly McQuillan

Introduction

The world is in crisis. Textile and textile-based form designers lack relevant design methods to design with a deeper understanding of the systems and futures thinking required to transform their industries. This essay aims to bridge the gulf between holism in theory and holism in design practice. Building on my earlier explorations of holism in practice (McQuillan, 2020; McQuillan & Rissanen, 2020), I define Multimorphism as holism through practice that encompasses multiple scales, forms, times and perspectives, that ranges from nanoscopic material behaviours to the social and environmental contexts the materials and outcomes exist within. In this context, we can view textiles as a system of materials that emerge through fibre-yarn-textile-form interactions, and, I argue, the greatest potential for any textile system can be found when the design and fabrication of these occur in symbiosis. Moreover, this symbiosis is a differently scaled version of the interactions between material, textile, product, industry, society and ecosystem. It can be read as a tangible manifestation a possible link between circularity (MacArthur, 2013, 2019; Stahel & MacArthur, 2019) and material-centred design models (Karana et al., 2015; Tandler, 2016). While these interconnected ways of thinking can transform how we design, make, use and recover textile-based form, we lack the design methods and examples to support this way of thinking and working.

The Circularity Gulf

'The majority of the environmental issues caused by the fashion sector are endemic, not incidental. They are a consequence of how the current model is structured. The better the sector performs, the worse the problems will get.' Fletcher and Tham (Fletcher & Tham, 2019)

In the circular economy waste is designed out (Stahel & MacArthur, 2019). However, this has mostly occurred through reimagining product use and supporting recycling. The fashion and textile industries are exploring circularity with some enthusiasm; however, the holism required of circular design is complex and unwieldy in this famously siloed industry (Whitty, 2021). To ease management and lubricate the supply chain, the fashion and textile industry divides the actions required to make a garment into smaller parts[1]. While superficially pragmatic, the silos limit the implementation of circularity due to the lack of holism in practice. The industry is provided with theory and theoretical models for circularity, new materials and machinery, critiques about its treatment of its workers, but limited examples of how design interacts with these together in a system in practice (Dokter et al., 2021; Sumter et al., 2020). Brooks et al. (2018) argue that the

[1] See pp. 122–123, Forty, A., & Cameron, I. (1986). Objects of Desire: Design and Society Since 1750. Thames and Hudson.

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industry's attraction to recycling is because it does not require holistic changes such as a reduction in resource use or a significant change in design processes, supply chains or consumption habits. Radical transformations are disregarded as too disruptive to the economy and industry. Because the circular economy is viewed through this western, anthropocentric lens, many of the biggest opportunities to mitigate the threats to humanity's experience and existence are missed.

Designing in a crisis

Design's particular view of the world has shaped, literally and conceptually, the forms and details of the material world. The contemporary fashion industry's methods are the result of hundreds of years of development and practice and have recently transformed into the fast-paced beacon of (aesthetic) innovation that it is today. These methods are primarily situated in the context of cut and sew (C&S) – and these approaches are due to the technological limitations of constructing three-dimensional (3D) garment forms from two-dimensional (2D) materials. The streamlining and standardisation of C&S methods have been governed by cost and speed of production. Such variables are the result of a destructive world view; therefore, the worldview, system, the methods and evaluation matrix need to be questioned. There is a gulf between the conventional systems of the fashion and textile industry and the actions needed to ameliorate its significant adverse impacts.

Stuck between the need to transition to circular economies, the baked-in nature of issues such as waste and resource overuse and expectations of the users of their products, many designers utilise ways of thinking, design methods and evaluation frameworks that are no longer fit for purpose. Yelavich and Adams (2014) articulated the difficult position designers are placed in, writing in Design as Future Making that 'designers are increasingly being called on to contribute their particular knowledge and experience to the hornet's nest of contemporary crises exacerbated by the habitual default to obsolete systems'. Clearly articulated knowledge and examples regarding how to navigate this complex circular design-focused space (Sumter et al., 2020) is missing.

In my nearly 20 years of experience advocating for sustainability and circularity to be included in fashion design education this challenge is replicated. It is common for these issues to be addressed in theory, but in design practice limited to making 'better' material choices. One colleague, when discussing where to situate knowledge on sustainability in design master's level curriculum, argued that the best place is for it is in theoretical courses. 'Afterall', they said, 'you can't prototype "sustainability"'. Furthermore, this push to extract the personal experience of practice from research is reinforced the more senior I become in academia. Many senior academics are not encouraged to work 'in the lab or studio' as that is something PhD and master's students should 'do' for us. However, in my experience of making design theory (Redström, 2017), if we divorce the personal experience of practice from 'real research', particularly in the context of sustainable and circular design, we miss the fundamental role that prototyping and making plays in deeply understanding what we do and could do.

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How can we prototype 'sustainability?

So, how can we prototype 'sustainability'? We have been prototyping 'unsustainability' since the dawn of the industrial revolution. This essay argues that prototyping is one of the most effective places to situate, experience and generate deep, interconnected sustainable thinking. Designers and researchers of physical outcomes need to move between the wider system and its implications, and the specific materiality of the outcome and its implications, while being bold enough to challenge existing frameworks of evaluation. To do so, there needs to be ways of understanding practice and evaluating outcomes in the context of the holistic change required.

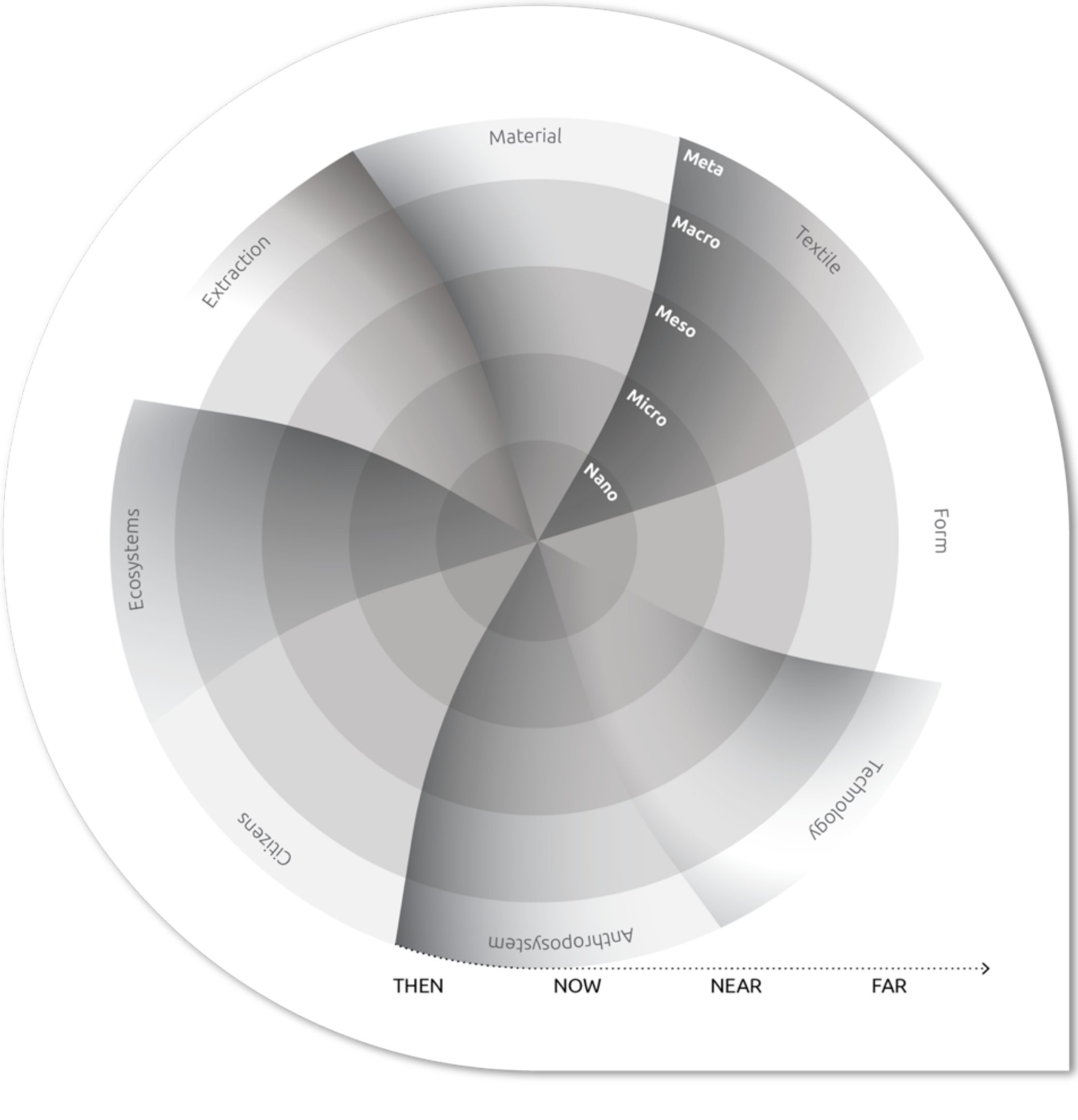

Figure 1: The Multimorphic Textile System model traverses Material-Human-Ecology across time and scale, and an 'ideal' holistic product would positively impact on all areas.

There is no 'correct' place to enter the Multimorphic Textile System (MTS) model (Figure 2.1). In the model as in reality, all factors are situated and interact across scale and time. We can divide the model into four segments (Figure 2.2): materials have properties that interact in textile systems; textile systems are constructed in and for anthroposystems[2]; all anthroposystems exist within ecosystems; and ecosystems provide us with the materials we use. Notions of scale are relative (consider what is micro in the context of material and compare this to micro in a textile factory), and importantly, things change over time. The more of the model that is traversed in a design process, the more multimorphic, holistic and 'sustainable' an outcome can be[3].

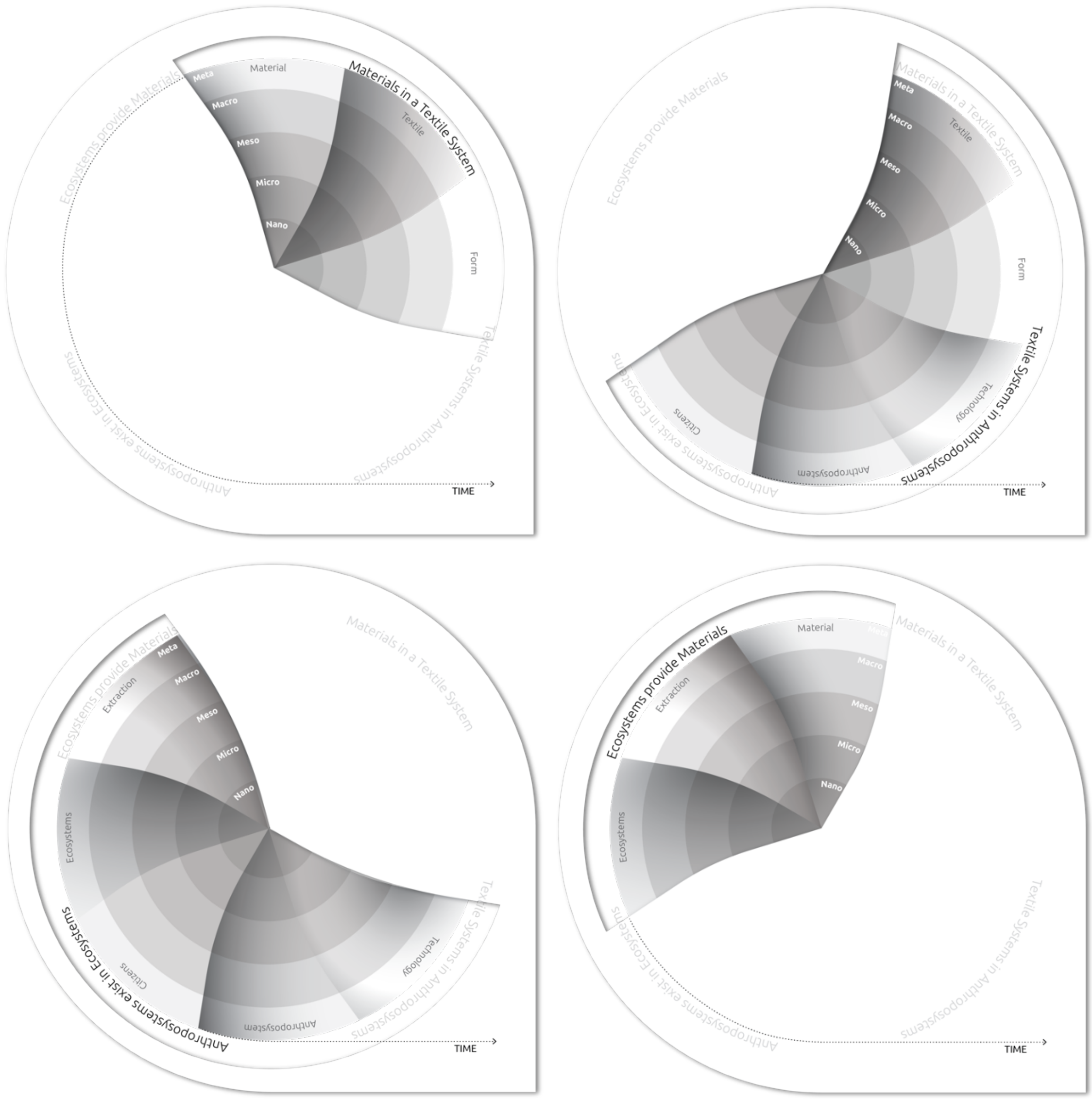

Figure 2: To simplify use of the model we can divide it into 4 zones. A: Materials in a Textile System. B: Textile Systems in Anthroposystems. C: Anthroposystems in Ecosystems. D: Ecosystems provide Materials. The development of a physical outcome can begin anywhere, but all four zones must be traversed.

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[2] Santos, M. A., & Filho, W. L. (2005). An analysis of the relationship between sustainable development and the anthroposystem concept. International Journal of Environment and Sustainable Development, 4 (1), 78–87. Santos and Filho defined the (if not the definite, then it should probably be 'anthroposystems') anthroposystem as encompassing all human systems and is a concept that 'forces society to think in terms of sustainable human systems, not just sustainable economic development'.

[3] While the examples provided in this chapter are specific to textile-form design, it is proposed that a broader application of Multimorphism might be possible for a range of other design practices which build (or can build) their designed things up from basic matter across multiple scales, temporalities and perspectives. This could be called Multimorphic Design Systems (MDS).

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The MTS model can be entered from any point. As designers typically explore tangible materials, textiles and form, this may be a comfortable place to begin. When examining a tangible outcome using the MTS model, knowledge embodied in it can overflow into adjacent zones in the model and back again and so progressively connect material practices to more abstract notions of anthroposystems and ecosystems. When examining material, perhaps considering its functional benefits due to microscopic features, directly adjacent either side we can see extraction and textile. We could ask, how can we utilise this material in a textile structure to amplify its functional performance, and how we can manipulate the processes of extraction to improve its environmental impacts? Conversely, theoretical knowledge about ecosystems can progressively be embodied in physical outcomes and back again. We might begin by knowing that polyester microplastics enter our ecosystems via laundering and wearing and then consider cultural notions of cleanliness as enacted by everyday citizens. Working our way around the MTS model we might then consider stacking technological processes to capture microplastics, with forms that require less washing, made from textile structures that lock in more of the fibres. The model discourages both 'drop-in' material or technological solutions, and 'awareness raising' or other cultural actions in isolation. Problems and opportunities are encountered through the making process in ways that a solely theoretical understanding cannot reveal, and without considering wider and longer-term implications of the things we make, we cannot hope to transition to a circular future.

Next, I will discuss some of the experiments conducted in my PhD and subsequent research to provide tangible examples that illustrate how my emerging understanding of holism in practice was experienced, and in doing so articulate MTS as an emerging method for circular textile and textile-form design research and practice.

Unfolding holism in existing processes through prototyping

The experiments in the following section explore the current system – where fashion designers are trained to frame their practices at the intersection of textiles as a raw material, form for the body, industry and users. These practices are multimorphic, everything is interconnected, but designers and industry act as though they are not. Waste in industrial contexts is treated as a management problem; yet its origins are in the aesthetics and 2D patterns of the garments. The field tests aimed to interrogate this origin, exploring new methods and the implications of eliminating textile waste from the production of clothing and other textile-based forms at the pre-consumer stage. Two field tests are described which apply waste reduction strategies in the design and marker-making processes, exploring the role various prototyping processes had in unfolding the participants' understanding of holistic ways of thinking.

Experimental Field Test 1

Experimental Field Test 1 (EFT 1) tested zero waste design strategies in the context of a large, low price, high volume high-street brand (Fast Fashion). EFT1 collaborators were McQuillan (design researcher) and contracted marker-makers, while buyers and technical designers from the contracting company observed, and later evaluated the outcomes.

The collaborators worked over two days to co-create a lower waste version of an existing style using a predetermined fabric width and garment pattern. Fundamental zero waste design concepts were introduced to the marker-makers and technical design team in a hands-on workshop working with paper to explore yield improvement, while discussing the context of various actions, decisions, and roles. The initial prototypes from this process were paper models that reveal the direct relationship between efficient fabric use and garment form. Three different possible outcomes were developed, one of which added a single seam, but reduced material use by 26%. These were sampled and 'costed' by the buyers and technical designers - an evaluation process that prioritises economics above all other factors. As the cost of sewing one additional seam outweighed the savings made through the significantly reduced material yield[4], none of the proposed changes were made.

Experimental Field Test 2

EFT2 tested methods and processes for the implementation of a zero waste design through the entire supply chain of a large sustainable outdoor brand. Prototyping holistic processes in this field test revealed deep-seated problems with existing industrial systems.

Experimental minimal waste digital prototypes were developed using the supplied garment pattern and a 'digital twin' of the fabric for an existing, high-volume style. The company tested the digital samples for improvements in yield. Promising designs were progressed from a digital approach to a conventional physical sample making process. Successful design strategies were developed collaboratively with the company technical design team and factory staff in Colombia. Samples were developed, tested, and sewn collaboratively with factory staff on the factory floor, an important step as pattern pieces for zero waste or low waste designs may be unconventionally shaped, making co-development important.

The team continually evaluated the design outcome and then passed the minimal waste, low yield version up the company hierarchy for further evaluation. At this stage the Head of Design (who was not involved with the development process), made small changes to placement of seams, which returned yield and waste percentage to the original figures. The resulting design, which carries all the aesthetic outcomes of the minimal-waste design process but none of the material savings that guided the design process, was approved for production.

Role of prototypes in mapping the present.

The prototyping process was key to unfolding holism in EFT1 in two ways: providing agency to undervalued skills, and increased comprehension of the impact that siloed roles have on sustainability goals. Workshop participants were contracted marker makers who usually have no input into the design of the products they develop markers for. Prototyping enabled us to work through assumptions and into a shared space created by the making. As the workshop progressed the marker-makers expressed that they could see the value their specific skill set brought to the design process, giving them energy and, importantly, agency. For the wider team that included buyers and technical designers, as the crude paper prototypes physically embodied the connection between design and waste in production, they deepened understanding of the unseen but

[4] Because the cloth used for this style was so inexpensive.

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symbiotic relationship between the actions of the garment designer, and how these impact on the outcomes that marker-makers are held responsible for.

Koskinen and Krogh (2015) state that design researchers see prototypes 'like hypotheses in science' while design and industry regard them as 'preparations for production' (p. 124). In zero waste design practice they can be both. In both EFT 1 and 2 the development of production prototypes also manifested the connections between the conceptual and the material. In EFT 2 an apparent conflict emerged between the technical/performance requirements of garments made for outdoor activities and the design research goals of the project, especially regarding the emergence and establishment of aesthetics. The existing design is an aesthetic choice resulting from decades of evolution driven by technical and functional considerations. The aesthetic of the minimal waste version, by comparison, was a dialogue between these existing models, and new methods (zero waste design) that respond to the climate crisis. While conventional garment design processes use digital prototyping primarily to develop fit and aesthetics, or for presentation and sales purposes, in EFT2 it enabled thinking-through-process to occur, providing simultaneous understanding of the process of making and its expression, in the context of the structures of the system being explored. The digital-physical zero waste prototyping process in EFT2 was a frustrating one, continually revealing the mismatch between linear expectations and holistic processes, manifested in a (digital or physical) object. Despite this difficult negotiation a suitable outcome was successfully developed. However, the conventional and somewhat external (to the design development) process unmade the improvements achieved that addressed wider sustainable goals. By attempting to take a holistic prototype through the existing linear process, areas of tension were revealed, and when we see and experience this tension through a design process, manifested in a prototype, the call to action is strong.

Zero waste has two interconnected facets: it is both a design method and a way of thinking. The decisive constraint of 'zero waste' enforces a holistic way of thinking through practice, and in doing so reveals in established practices an unwillingness to change, even when those changes achieve the industry's explicitly stated goals. When research is situated in industry itself prototypes have different roles for these two intersecting spaces of design practice and design research. At first it can seem as though the design research goals of the prototyping were limited by the industry system. However, what was prototyped wasn't only a physical design, but also the holistic interactions of a system. Prototypes are the physical manifestation of unsustainable and sustainable systems, and we can use them to understand the impact of our actions within systems. In the context of design practice in industry the existing norms of the system usually prevail despite stated goals of circularity and waste reduction. While in design research these existing systems provide an opportunity for inflection - a chance to pivot and challenge the industry to both see itself, and act, differently.

Prototyping the Future: Woven textile-forms

The fashion and textile industry requires holistic ways of working that reject established processes and understandings of aesthetics, conception, and production. Textile-forms are textile things in which form and surface are simultaneously conceived of, and constructed in the context of their methods of conception and systems of creation. Woven Textile-form (WTf) (McQuillan,

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2020; Piper, 2019; Piper & Townsend, 2015) enables yarn to weave directly into textile-form and can ameliorate some of industries unsustainable practices, such as cut and sew and over production. There is a lack of foundational knowledge in how to design for complex WTf systems. Most examples build out from what is already understood about expression, technology, form, material, or yarn, which emerges from existing systems of design and production with an anthropocentric view of the world. However, even though many of these examples are limited in their scope, the inherent entanglement of WTf's enforce other ways of thinking the provide an opportunity for transformation through practice.

Making Space

Since knitting entire garments with minimal waste is already feasible in industry (See *Knit&Wear by Stoll*; *WholeGarment by Shima Seiki*), this research explored a whole-garment approach for weaving. Prototyping began with an exploration into foundational design and production techniques while considering how specific approaches might benefit sustainability and circularity goals.

Digital tools (such as CLO3D, Illustrator, Photoshop, ScotWeave) were used to understand the potential relationship between 2D woven structures and 3D garment form – later embedding 3D form into multi-layered textiles. The digital prototyping process enabled a high degree of experimentation with low risk and time commitment. Since I had never woven on a digital jacquard loom before, simple multi-layered woven samples developed understanding of the textile design and programming processes for multi-layer textile structures. This early-stage prototyping sought to develop digital and analogue processes, while also connecting the form and textile knowledge required to operate in this interstitial space.

T-shirt series

The T-shirt series of experiments designed recognisable t-shirt forms that are zero waste by making 'space' between the layers of fabric woven on a digital jacquard loom (seen also in Figure 3). The T-shirt was selected because it is recognisable but difficult to achieve utilising existing conventional zero waste pattern cutting techniques, while having enough topological complexity to provide a challenge for the developing method.

A standard t-shirt pattern was stacked in CLO3D to mimic the multiple layers possible on a jacquard loom[5]. The Map of Bindings[6] (MoB) resulted in a rectangular woven textile with standard 2D t-shirt pieces embedded within, and once cut and separated, the pieces were stitched back together in a conventional way to make a standard t-shirt form. This yielded a result that was somewhat analogous to fully fashioned knitwear – without waste, utilising standard machinery, and requiring a standard construction process after cutting.

The experience of standing at the loom while the t-shirt was woven was profound – because I knew exactly what was being interlaced in the warp and weft, it felt as though I were 3D printing

[5] Borrowing from the structure of Double weave.

[6] Map of Bindings is sometimes known as the weave 'artwork'. 'Map' is more appropriate here as maps are a 2D representation of 3D space, and these Map of Bindings serve the same function.

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a t-shirt out of yarn. I realised I was constructing a woven garment using an additive manufacturing process. The practice of then cutting the fully fashioned pieces and sewing the t-shirt form was laborious and drove the direction of the subsequent experiments. The third and fourth t-shirt iterations therefore reduced or eliminated the post-weaving construction required and resulted in outcomes that construct a relatively conventional t-shirt form with either two, or no, seams required. I was prototyping 'sustainability', and in doing so it enabled me to critique and understand the implications of the methods as they were developing.

As with the cut and sew examples in EFT1 and 2, digital prototyping here enabled a different kind of simultaneous understanding. As weaving entire garments using this design method was novel, digital 2D and 3D prototypes provided low-risk space to explore design concepts. Basic comprehension of jacquard weaving theory could be rapidly digitally developed and applied. The digital design processes revealed both the construction process and its relationship to the surrounding systems of production and use. For example, the second iteration of the T-shirt series stacked larger garments within the confines of a 40cm loom repeat. Unexpectedly, the 2D to 3D animation revealed unfolding as a method to embed multiple adaptable forms within the textile, suggesting new relationships could be embedded for citizens to have with their garments over time.

Tools shape prototypes, both digital and physical. Programming the first T-shirt iteration in Scotweave provided an applied case to understand the software and theory of weaving in use. Once off the loom, the cutting and sewing processes required revealed the prototype was more fully fashioned than 3D woven. Designing within loom width constraints developed new solutions. Further extending this notion of thinking-through-process, the digital making process revealed a sliding action when rendering, that then developed a sliding-expanding binding. Without the peculiarities of the digital animation function in CLO3D, it is possible that this specific application would not have been developed. The unconventional use of digital technology revealed another way of seeing and understanding the digital prototype, which led to novel methods being developed. The process of digitally and physically prototyping provided unique insights into the developing processes that may not have emerged or been noticed without engaging fully with the making process. While the MTS model challenges the designer to work through all 4 segments, to consider adjacent zones and develop alternative ways of working with materials and tools in the identified context to meet holistic goals.

Prototyping the Near future: Trouser

These experiments developed a weave-able, wearable trouser form with conventional design elements. McQuillan and Milou Voorwinden (multilayer jacquard design specialist) developed design processes to enable the transferral of information between disciplinary specialists and ways of thinking, and then use these prototypes and newfound knowledge to engage with external weave and finishing experts in the luxury market.

All prototypes were woven on looms with a polyester yarn warp[7]. We explored the use of circular (recycled denim yarn), and local fibres (wool yarn) in the weft, which, unlike the warp, could be easily controlled and changed. The prototypes bracketed the application of the developing design-to-weave processes, with a strong focus on waste reduction, automation and weave program systems development which could later be applied to local, on-demand, circular systems of design and production.

The trouser form was designed digitally, generating both a 3D digital model and annotated 2D MoB which was used to communicate the textile-form concept with Voorwinden. We then tested materials, yarns, bindings, density, and suitable systems for managing the complexity inherent in multimorphic outcomes. Voorwinden had some experience programming woven textile-forms, so drew on this existing knowledge to develop eight development prototypes.

New knowledge and design theory emerged out of the prototyping process, and the prototypes themselves proved useful when explaining the new method to a luxury fashion brand. They are a vertical manufacturer - from yarn spinning, through fabric manufacturing and finishing, and garment design and production, almost every part of the supply chain is in physical proximity. At the time of writing, this collaboration is at an early stage, however the prototypes are useful vehicles of communication between McQuillan, Voorwinden and the various experts located at the company. Despite differences of language (between the team three languages are spoken), the physical prototypes are proof-of-concept as well as teaching devices, enabling mutual understanding when negotiating complex and holistic practices. A key utility of the prototypes was in aiding communication between the research undertaken in a 'lab' context and research undertaken in the 'field'. The physical tactility and familiarity of the prototypes makes them embodiments of the process and therefore learning tools for all involved. The weave structures are in many ways simple (mostly twill weaves, with a variety of layer arrangements), also the form is recognisable, they clearly result in a trouser, and the tools and materials used (jacquard loom, yarn, the form and weave software) are standard. However, the way they come together is unfamiliar. So, in this context the prototype pulls together what is known and translates it through an unfamiliar process into something we understand. The WTf prototypes are conduits between the 2D form language of a weaver and the 3D form language of the form designer. The prototypes are in this way multimorphic things that communicate a multimorphic process.

Prototyping the Far future: Experiment 0 (trouser)

This stage of prototyping explored processes of thinking through form and textile which introduced time is a key component of the design process. Active Textile Tailoring (Tessmer et al., 2019) explores whole garment knitting and heat-reactive yarn to produce garments from and for the torso. Experiment 0 (tunic) explored similar processes but for weaving and with a more open aesthetic brief, moving beyond function. Here the form embedded in the weaving process can be further modified over time through the use of a mould and heat in interaction with heat-reactive yarn to control 3D form (see McQuillan et al., 2021). Experiment 0 (trouser) refined the

[7] This was a limitation driven by availability. This is a common occurrence when prototyping particularly for the near and far future – often what you would ideally use, is not readily available, and consideration for substitutes must be made.

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new garment design and construction processes of Experiment 0 (tunic). Holly McQuillan, Karin Peterson and Kathryn Walters embedded time as a design element in the development of the trouser textile-form to expand the design and production method, aesthetics and life cycle of a trouser.

The MoB for the trouser was designed so that it would fit within the 40cm repeat of the loom used, while expanding to fit the 3D mould with enough room to then shrink when heat is applied. Digital samples explored the potential aesthetic and form results from the proposed MoB interacting with the mould (Figure 3). Previous prototyping had shown that to maintain a high enough fabric density for structural integrity, the MoB should split the trouser into left and right legs, to be woven separately. This halved the number of layers required, which in turn doubles the fractional density[8]. Only the crotch seam needs to be stitched to complete the form, and this interaction of weaving factors, form outcomes and finishing methods raises questions about how to balance durability and automation in the design process. Sections of the MoB were woven at 1:1 scale to test the bindings, and after adjustments a full-scale trouser prototype was woven using cotton warp, with alternating cotton and NSK weft yarn. After the crotch seam is sewn the form can become four different styles: it is wearable as is; can be shrunk on the 3D mould it is designed for; shrunk on a body to fit; or shrunk in a domestic dryer to activate all of the textile-forms shape change potential (Figure 4).

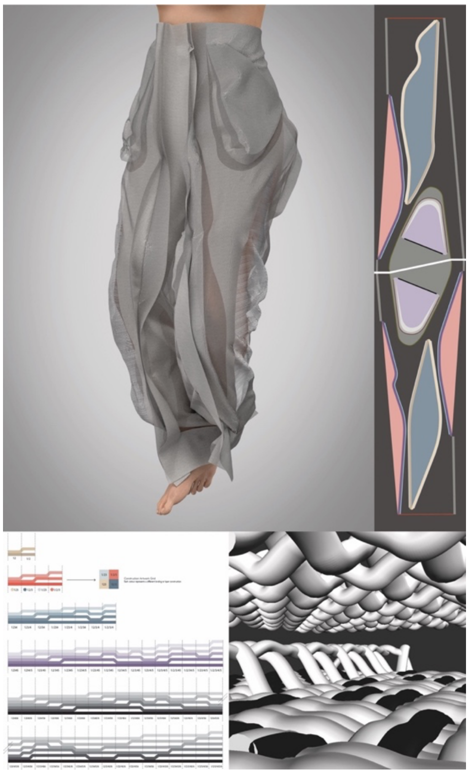

Figure 3: Top left: 3D model/ Top right: 2D MoB. Bottom left: Layer sections. Bottom right: Micro-scale digital textile systems. The digital prototype and related MoB, and micro digital textile systems embody plan and elevation views in three and two dimensions as well as change over time, and meso (top left) to micro scales (bottom right).

[8] Fabric density in unfolded 3D form is a function of the total 2D fabric density divided by the number of layers – *Fractional Density.*

Figure 4: Top left: Trouser on loom. Top middle: Loomstate textile. Top right: Detail of yarn behaviour after cutting. Bottom left: unshrunk trouser. Bottom right: The same trouser shrunk in dryer. Darker cream yarn in weft direction (most easily seen in third image) is NSK heat reactive yarn, lighter cream is cotton weft and warp. This colour difference reveals the variety of layer composition in the resulting loom state textile that causes complex behaviours to emerge once 3D form is released through cutting and heating.

Prototyping Experiment 0 (trouser) unfolded my understanding of the potential of temporality in the context of woven textile-forms. They are an example of an animated textile-form (Buso et al., 2022) which embed in them new production methods and use practices by treating fibre-yarn-textile-form as an interconnected system of material interaction over time. It tested and revealed the potential for 'programming' difference in a yarn with uniform behaviour by manipulating the weave structure. The processes of prototyping also revealed the joy in animating their transformation, as well as problems in controlling the application of heat, while their unexpected expression (often people assume they are knitted) challenges expectations of aesthetics that are the result of new, holistic processes. The trousers also embody a contradiction and an invitation in one: the use of polyester heat shrinking yarn with cotton warp and weft is inherently unsustainable, however the possibilities of that mechanism for embedding change over time motivates future explorations in alternative shape-change fibres.

Role of prototypes in connecting scale, time and material.

Everything about the things we make is cultural, political and ecological, is complex, messy and interconnected. Yet our design methods and ways of thinking about materialised things focusses on aesthetics, cost and ease of production - conventional design's 'critical zone' (Jensen, 2021). Designers often concentrate on the scale and timeframe they routinely operate at: the scale of the material or the body, or the timeframe contained in a user's experience of wearing a static garment. But in fact, design's critical zone expands to encompass ecosystems and use across time. Jensen proposes a rethink of the notion of scale in 'such a pragmatic manner that it becomes useful for design… as a 'gestalt' that at times may relate to geographical hierarchies and spatial borders, and at other times to mental relations and imaginaries' (pg. 46, 2021). This pragmatic/abstract relationship is a useful one when differentiating between interlinked but differently expressed multimorphic fields - that of pragmatic Materials in textile systems (Figure 2A) or Textile systems in anthroposystems (Figure 2B); and abstract understandings that traverse ecological time and scale: Anthroposystems exist within ecosystems (Figure 2C); and Ecosystems provide us with materials (Figure 2D). The discourse has situated sustainability and circularity in theory, as abstractions and ideas, however, as all physical outcomes embody these ideas, if we don't do sustainability when designing, prototyping and making, it cannot happen anywhere else.

Conclusion

Circularity requires practices which embrace holistic complexity, while the processes commonly used in the fashion and textile industry are linear, resulting in a mismatch of goals and outcomes. Prototypes that are the result of a linear way of thinking reinforce linear processes by prototyping 'unsustainability'. In reality, all design practice is multimorphic - but our attempts to solve the big, complex issues we are facing fail because we do not treat everything as interconnected.

Conventionally, textile and fashion designers focus on matter at the meso scale, and for a single moment in the very near future. However, textiles – perhaps more so than many other products – have the ability to embody multi-scale, multi-time states. A designer needs to understand on some level the nano and microscopic behaviours that interact with the structure of the material (like the mechanism for wool felting as the tiny scales on the surface of the fibre are entangled). This microscopic fibre behaviour in a particular textile structure generates behaviours in a 3D form that exists as an object a human interacts with, which can change over time. These forms are made in an industrial and cultural context that has implications for ecology now and in the future, and the ecosystem is what allows us to grow[9] materials, build communities and exist in relative safety. All of this should be understood in a holistic, circular and healthy design and research process for textiles. We cannot expect to develop sustainable outcomes by avoiding prototyping sustainability. Prototypes when approached as a holistic practice hold within them the past, present, and future while also providing the means to evaluate, vision and enact proposed futures. In this way prototypes can be ideal conduits for holistic ways of thinking and design theory - if we let them be.

A Multimorphic Textile Systems framing of prototyping provides a way of traversing complex scales and spaces by linking tangible design practices for textiles at a range of scales in material and textile systems (something designers inherently understand) with more abstract and theoretical notions of holism in anthroposystems and ecosystems. In MTS, prototypes are mediators of this knowledge. In the complex intertwined fibres and yarns, and the interstitial spaces between layers that change with interaction and use, is a scaled understanding of the broader contexts they were conceived within. Within the textile-form is the soil and farmer that grew the fibre, the machine and technician that wove it, the person who will wear them, the

[9] Alternatively, we could reach back into prehistory to extract carbon deposited millennia ago to make polyester that ends up in our water and tissue as microplastics.

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environment that will carry its materiality until, eventually, it becomes earth again. Navigating all this is not easy, but, by 'staying with the trouble' that is often encountered when prototyping sustainability, unforeseen outcomes and possible futures emerge. We can lean on their pliable, ordinary, everyday textileness (Gowrishankar et al., 2017; Buso et al., 2022) to communicate complex and multi-dimensional relationships - visualising possible futures and providing the means to achieve them.

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