Hybrid zero waste design practices. Zero waste pattern cutting for composite garment weaving and its implications

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Abstract: This practice-based design research explores methods of eliminating textile waste through utilising zero waste pattern cutting to expand the outcomes possible through composite garment weaving and speculates as to the implications for the wider industry and society. Employing a hermeneutic phenomenological approach, I tested known strategies in the context of industry and responded with new emergent strategies to the challenges that arose. The findings that emerged from the iterative design practice, and surrounding discussions and reflections, inform the experimental design work that follows. It is this experimental 'future-making' that is the focus of this paper, which outlines foundational pattern cutting theory and methods for an emerging field – composite garment weaving – as well as findings relating to the impact and use of technology in the fashion industry while bringing into sharp relief the inherent conflicts that exist within the fashion system.

Keywords: Zero waste design, Composite garment weaving, Technology, Circular design, Sustainable fashion

1. Introduction

Typically, 15%-25% (Rissanen, 2013; Runnel et al., 2017) of the cloth needed to produce a garment is wasted due to deeply entrenched and complex conventions of design, pattern cutting, and production practice, all of which are reinforced by dominant and problematic business models. The combination of a massively globalised and fragmented industry, and fear of a loss of competitiveness if the realities are revealed (Ditty, 2015), leads to a general lack of transparency in the fashion industry. In a recent 2018 report by Fashion Revolution, the highest transparency level achieved was 144.5 out of a possible 250 points (Ditty, 2018). The demonstrable opaqueness of the industry makes comprehending the scale of the waste problem and then addressing it a herculean task, so most strategies have been applied only on a small scale. The inclination to want to scale up these, and other innovative sustainable strategies are understandable. However, this may fail to address the underlying consumption model which is responsible for many of the problems we face (Brooks et al. 2017).

It may seem we should write off the large-scale globalised model as a destructive one, but to do so would neglect to address areas of the industry that negatively impact on people and planet at a considerable scale. Perhaps we should look to brands who produce intentionally slowly and holistically, utilising ‘fiber sheds’[1], local production and natural dyers. The garments they produce are hand-made by those who have the skills to make themselves or bought from the skilled by those who can afford to pay for them. However, it can be argued that this small-scale approach fails to impact on the wider production and consumption issues the industry faces. Probably the best holistic solution to the problems we are facing in the fashion industry is addressed through circular design, assuming we apply it holistically, at all stages of the fashion cycle and not only at fiber recycling. Simultaneous respect for (re)use of resources and at least a flattening of consumption and production will be required to address the problematic waste issue we are facing – requiring us to not only change the way we use and discard materials, but the production methods we employ.

2. Aim

Hybrid zero waste design is a design approach that operates at the intersections of practices, and through it aims to reduce or eliminate waste from production while revealing new expressions. In this case, the intersection is between fashion and textile design and takes a simultaneous design approach (Townsend, 2004) where we realise in tandem the textile structure and garment/3D form. This practice is not merely concerned with designing objects or forms, but also the systems that this hybrid practice operates within. I agree with Tim Marshall (in Yelevich and Adams, 2014) who takes the view that design cannot act in isolation of the complex social, economic, and environmental issues that envelope it. Furthermore, this research exists (as perhaps all design should) in a precarious, and political space (Fry, 2010) – our current situation demands that we “confront an unavoidable choice: we either support the status quo or we chose a path of change.” (Fry, 2010, pg 1)

2.1 From field test to future making

The aim of these fields tests was to explore the limits and opportunities of zero waste fashion design practice in the context of the fashion industry and aimed to develop viable, manufacturable garment outcomes for two large garment design and producing companies. Employing a hermeneutic phenomenological approach, my research program (Redström 2017) takes the form of iterative ‘field tests’ within relatively tight design frameworks – where the initial constraints were set by the ‘field’ in which the tests took place. The findings that emerged from the back and forward iterations of the field tests and surrounding discussions and reflections (Schön, 1983) directly and indirectly inform the experimental design work that follows, it is this experimental ‘future-making' (Simon 1969, Yelavich & Adams 2014) that will be the focus of the second half of this paper.

3. Research Methodology

The beginning of this research involved two field tests, of different durations and goals, both within large garment companies which have sizeable globalised supply chains and operate within the

[1] Fiber sheds are a network of farmers, ranchers, land-managers, designers, ecologists, sewers, knitters, felters, and natural dyers, spinners and mill operators that have defined a strategic geography to work and create within. (*Fibreshed*, 2018)

conventional fashion system, predominantly producing using "cut and sew"[2] methods. I set out with the original intention to develop 'successful' products for these companies so that I could then report on my success in my PhD so others – be they designers, companies or researchers – might learn from my experience. In this section I will outline the nature of the field test and how they progressed, later reflecting on the experience, and outlining how this spurred my research in a somewhat unexpected direction.

3.1 Field Test One outline: Large high street clothing brand

The first field test was of short duration, lasting three days and taking place in Istanbul. I was asked by a large fast fashion company to work with a group of their freelance marker makers[3]. The company are known for their efforts to reduce the negative impacts of their garments; however, they are a brand where high-volume, low-cost garments dominate. I worked with teams of marker makers on a specified existing dress design, exploring a range of approaches and small changes to the design in order to dramatically improve garment yield and reduce waste, without change of silhouette or critical details. In this context, we developed three different possible outcomes, one of which reduced yield for the planned style by 26%, by adding a single seam. These modified garments and markers were costed by the company[4], however, as the savings they would make on material yield, were outweighed by the extra cost of sewing the additional seam – because their cloth was so inexpensive – they were not implemented.

3.2 Field Test Two outline: Large sustainable clothing brand

The second field test was of much longer duration and for a very different garment brand. In 2016 I led a zero-waste design workshop with a large American sustainable clothing brand. In preparation for the workshop, I was asked to redesign an iconic mid-layer fleece jacket using zero waste design principles to demonstrate to the team what may be possible. I presented this design while hosting the zero waste design workshop with the product team who suggested changes to seam placement, such as moving seams slightly for reasons of function, taste or aesthetics. When making these changes, both large and small, efficiency and yield returned close to the original.

Later, the team decided to embark on another project with me – redesigning a men's and women's technical fleece mid-layer. The project began "off calendar" meaning it would have a long development period, acknowledging the peculiar challenges this type of project faced. However, it was moved to be "on calendar" midway through the process, significantly reducing the time available to develop effective solutions. An iterative process continued back and forward for many months, with shifting explicit[5] and implicit[6] constraints playing an ever-increasing role in the decisions made. Despite the challenges presented through constraints, the designs progressed satisfactorily enough

[2] Cut and Sew garments are constructed using patterns to cut garment pieces from an existing roll of cloth (knit or woven), and then sewn on a sewing machine. The process is time consuming, complex and wasteful compared to fully fashioned knitting for example.

[3] Marker maker takes the provided garment pattern and works with specialised marker making software to achieve the most efficient layout of the pattern of fabric for production. They have to consider the full-size range, volume of the production run, cutting table size, fabric behaviour (shrinkage for example), and directional print or grainline. They do not generally have input into the design of the garment, except in exceptional circumstances (where the garment pattern pieces are too large for the fabric width for example).

[4] This is where the total cost of the garment is calculated in detail, including all material use, trim and thread use, the time required to manufacture the garment.

[5] Factors which were able to be easily communicated and answers found – such as fabric width, size and grading requirements, limitations of manufacturing equipment

[6] Factors which were much more difficult to articulate – such as 'house style' or the hierarchy of what was important in a given design.

that the company arranged for the design and technical design team, and me to travel to one of their factories for a week of intensive collaborative work. This kind of at-factory design had never taken place in the company before, and in a short space of time, a significant amount of work and related breakthroughs were achieved. The outcome of this week was a working sample of both the men's and women's technical garments, with significantly lower yield than the original. However once assessed by the wider team, and suggested changes to the aesthetic and fit of the design were actioned, the yield and waste was only marginally improved on what it was initially. The company is proceeding with this version of the garment.

4. Reflection – The desire for change without change

4.1 The value of fabric waste

A key finding in Field Test One was that when using a conventional production process, within a high volume, low-cost context, reducing yield and improving waste is not a valuable investment in time and resources if the material cost is not a significant part of the cost of a garment. The changes required to the profoundly ingrained system are too significant for them to be worthwhile unless there is motivation outside of a financial imperative. The business model constrains meaningful improvement and change.

In the process of working through Field Test Two, I had conversations with the wider team at the company regarding textile use and waste. I discussed with textile designers and material developers the possibility of specifying fabric width but this was considered infeasible. At times I found it compelling to attribute a value to the waste generated, but due to trade agreements, effectively the company only has a moral responsibility for the waste, this is a responsibility they take seriously but can be challenging to implement. In general, information about the volume of waste generated by the production of garments, the actual markers, yields and patterns used are closely guarded by many factories. They profit off the difference between what they quote and what they use, and when margins are tight, this revenue can be important. Waste it seems in an inbuilt component of the fashion industry.

4.2 Hierarchies in design and production

Field Test Two revealed that this kind of work cannot be rushed, and requires holistic approaches and partnerships from all stakeholders involved. It is of note that the most rapid and successful period in the design and product development process was when many of the stakeholders were working together in the same space and time. It is essential that design language is confirmed and articulated, and production limitations known and challenged – such as what aspects of the design and production are negotiable, what is not – and when the designer, line manager, pattern cutters, production managers and technicians are working together these can be more easily addressed.

The conflict between the holistic requirements of a zero waste design process which is situated in design aesthetics and production simultaneously (and so requires a balance and understanding of both), and the siloed, hierarchical and linear design process the company was used to working with was another clear roadblock. There seemed to be a lack of understanding of the spatial reality of a given garment design using conventional production methods – both company's wanted the design to remain the same, but for it to somehow take up less space – change without change. But zero waste design in not magic, and cannot be considered merely a design or pattern cutting technique. You could say it *enforces* a holistic way of working which in many ways is unlike the conventional fashion design system. The field tests can be seen as both a failure of my zero waste design approaches to adapt to the industries rules and a testament to the inflexibility of the industry, a failure to change even when acknowledging the need to change. Despite these tensions, this research does demonstrate that zero waste design, when implemented into the wider industry, can enforce a different way of thinking, allowing us to ask different questions and potentially fine alternative solutions.

A key finding in the field tests was the realisation of the degree to which the constraints of industry prevent meaningful and responsible innovation. Extensive reflection has led to me questioning the relationship and hierarchies between fabric and garment within the design process. This questioning takes place through an experimental iterative process, where I was able to combine a newfound understanding of the digital jacquard loom, with my prior tacit (Polayni 1966) and explicit knowledge in the field of zero waste garment design. This has revealed the beginnings of foundational pattern cutting theory and new methods for an emerging field – composite garment weaving – as well as findings relating to the impact and use of technology in the fashion industry.

5. Conceptualisation – Future making aesthetics, production and economies

Simon (1969) and then Yelevich and Adams (2014) have worked to highlight design as an act of future making. They argue that as designers 'make' the future through products, services and interactions, design is intrinsically social and utterly political, and therefore our actions as designers need to consider what kind of future we are making in doing this. The following section explores three avenues for considering the practice outlined in the remainder of the paper as future making.

5.1 Aesthetics and Production: Pattern cutting for Composite Garment Weaving

A common criticism of zero waste practice is the perceived lack of aesthetic control the designer has, this was raised in discussions with staff at the two field test companies – and it does require a more nuanced negotiation between 3D form and 2D pattern than conventional fashion design practice where the 3D almost always completely controls the 2D pattern. Though in practice it is rarely this straightforward – it is usually taught that pattern cutting is in service of the design sketch, and so the process of sketch to pattern to garment is clearly established. For most fashion designers the behavior of the textile is understood concerning its existing aesthetics and structure. Textiles are selected based on criteria – such as knit or woven, weight, handle, drape, colour, and print – to best serve the intended design. The vast majority of designers do not and cannot specify its construction. Additionally, most designers consider textiles to be two-dimensional structures, a single plane that in its simplest form can be hung as a screen, or perhaps manipulated into a 3D form to cover a chair, or make a dress.. However, what if we considered the creation of woven cloth as additive manufacturing for garment production? We more easily do so for knitted materials, but the same is true also of woven materials and forms. Our existing shallow understanding of the relationship between textiles and form limits the ways in which designers could transform our industry and built environment. I question how technology has and can further shape form-making, following some of the lines of inquiry forged by the work of Issey Miyake and Dai Fujiwara in A-POC (1999 - present), and recent explorations on digital composite garment weaving by Anna Piper (Piper and Townsend 2015), Jacqueline Lefferts (2016) and Linda Dekhla (2018). This reshaping of form-making has the potential to future-make the structure of the industry itself, and through that our social fabric.

5.2 Digital Crafting

Thomsen (in Yelevich and Adams, 2014) argues that understanding the behavior of the real material is augmented by the opportunities afforded by their digital representation (increase in variation and design complexity for example). "The term digital crafting suggests the intersection between digital design tools and the capacity for precision, variation and control within the craft tradition" (in Yelevich and Adams, 2014, p.61). By modifying their structure, we can discover new behaviors for existing materials, and use digital tools to expand on the possibilities this new understanding offers designers. The use of 3D modeling software is already having profound impacts on the representation of garments in the fashion industry[7], however, how can it impact on the design process, outcomes, and systems in which designers operate[8]? This research utilises 3D design software extensively, enabling the design of highly complex woven garments, even though the designer (me) had little existing understanding of weaving or weaving software. New technology can act as a conduit between fields – such as fashion design and textile weaving – which need to be able to communicate better, but lack the language needed to conceive of new forms and methods at the intersection of practices and fields of knowledge.

5.3 Economic Models – Circular design, Scale and Social Impact

Cut and sew manufacturing is a complex, time, body and material intensive process – and the most commonly used for garment production. In a conventional manufacturing model, the actions needed to produce a cut and sewn garment are divided up into an assembly line in large factories requiring many workers to produce a single garment in a largely un-automated process. Models which disrupt this have begun to be explored by London based Unmade, and by Adidas, in their 2017 “Knit for you” popup shop and factory. Both examples utilise interactive software to enable consumers to participate in the design of their garments and onsite whole garment knitting to produce the garment designed on demand. Reducing the steps required to produce garments, and in some cases eliminating many of the hand finishing processes involved, my practice builds on ‘Seamdress’ by Kate Goldsworthy and David Telfer (2013) which explored circular economies, mono-materials and laser-etched garments. By situating the majority of garment production processes in a single location – ideally, in a distributed model close to end-users – transportation emissions are reduced, and end users can witness the process of making garments.

It is important to consider the potential impact that this kind of automation will cause on the economies and livelihoods of current garment workers. The International Labour Office (2017) discusses these impacts in a report titled *New Automation Technologies and Job Creation and Destruction Dynamics 1* – making clear the potential benefits and costs they foresee with increasing automation. They estimate that as soon as 2030, 47% of all work in the US, and 89% of sewing machinists are at high risk of being replaced by robots and other automation techniques and that if these costs are not addressed in a timely way, the repercussions are severe. Any new development can have consequences those that develop them do not foresee or care to mitigate.

One way of ensuring new technologies do not have unforeseen impacts is, of course, to not use any. Favoring a transition back to slow, human-scale, labor-intensive, cottage industries, proponents advocated for natural dyeing, hand weaving and knitting, and home sewing of simple garments. A kind of ‘change by changing back’, these models seek to undo many of the technological and aesthetic changes wrought by the industrial revolution but like automation are not without negative

[7] The use of Clo3D by Balmain for their advertising using the world’s first digital supermodel is an excellent example of this.
[8] For more on this see Siersema, I. (2015) ‘The influence of 3D simulation technology on the fashion design process and the consequences for higher education’, in *Proceedings of Digital Fashion Conference 2015 Digital Fashion Society*.

impacts[9]. In response to Jamer Hunts (in Yelevich and Adams, 2014) critique of the "blindingly" "convoluted" scale of industry, I agree with Kamenetzky (1992) who argues for an economic model which is human in scale. Like Kamenetzky I do not advocate for a wholesale return to 'primitive' technologies "whose operation required large amounts of human energy" – I instead aim to help make a technologically driven future which reduces the scale of the industrial complex required to produce woven garments which would previously be 'cut and sewn' – a kind of high-technology-meets-cottage-industry model (see figure 1).

Hybridising the actions needed to make a garment (or chair, or building) enables me to produce innovative garments, both recognisable and radical. The approach could enable a circular model of production – produced with a single material and fibre, embedding details which are often glued (interfacing) or stitched (most commonly using polycotton thread) to the cloth. Eliminating the majority of the waste from the manufacture of the garments, reduces the energy needed to capture and recycle these fibres. By prototyping ideas to proof of concept stage utilising currently available technology, the digital, industrial jacquard loom, I propose and begin to materialise a future – first clearly articulated by Miyake (1999) – where engineered cloth/garments are produced primarily on the loom, on demand, potentially proposing new technological developments[10].

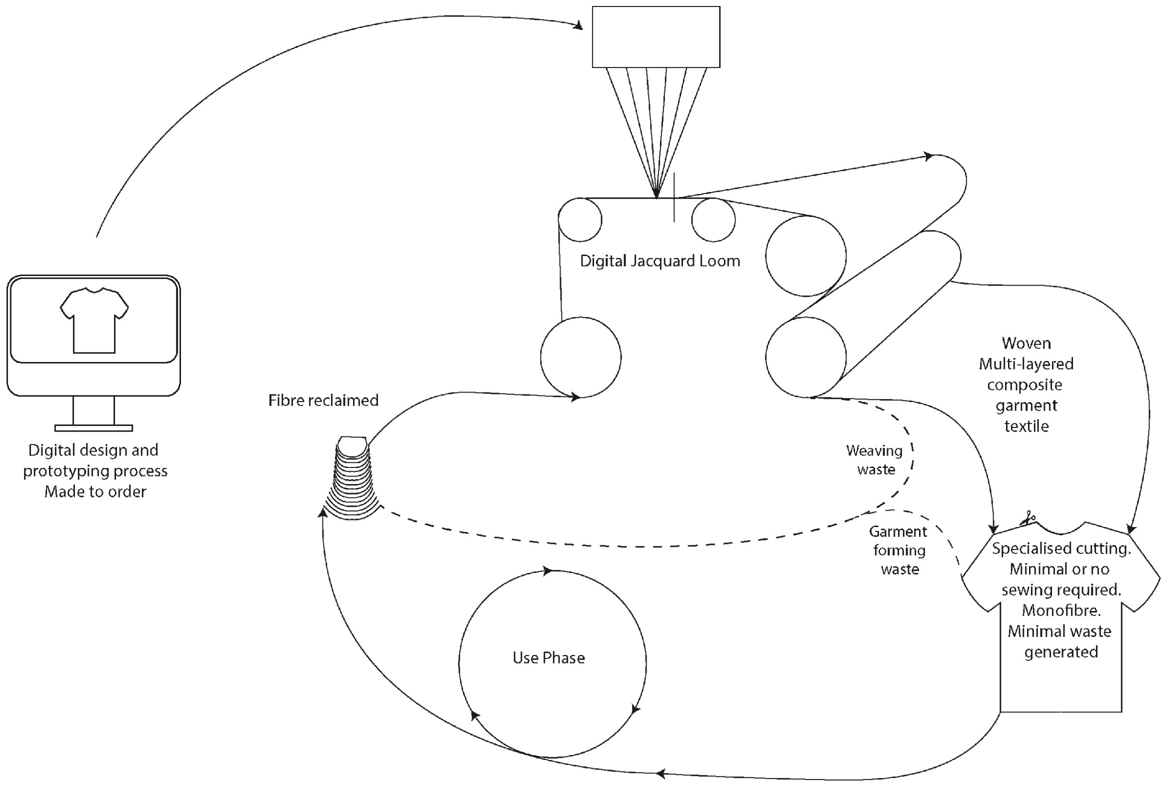

Figure 1. Theoretical circular model for hybrid zero waste composite woven garments.

[9] There are examples which prove small scale does not always mean only looking backward. Yoshiyuki Minami of Manonik (Minami, 2018) perhaps provides a good example for small scale with forward-thinking change – his work explores new methods of form making through weaving utilising small-scale and local processes – simultaneously significantly slowing and shrinking the scale of the industry while developing new methods of making garments that result in new forms.

[10] Such as highly sensitive automated cutting equipment.

6. Active Experimentation

T-shirt form

The next section explains my design process and workflow for designing the 3D form of a T-shirt, translating it to weave-able 2D structure, in order for it to once again be made 3D. I chose a T-shirt because it is difficult to achieve utilising existing zero waste pattern cutting techniques in a recognisable form. I explore the T-shirt form in three iterations, presenting it in detail for the first iteration, and subsequently exploring the sequence of limitations and possibilities that arise through iteration two and three.

6.1 T-shirt Iteration One – Stacking layers

To design the first iteration of the T-shirt, I utilised Clo3D and the basic T-shirt pattern available through the software. The use of existing conventional patterns was an attempt to achieve an understood and expected form, however, it also caused an inherent front/back flattening of the body form because a conventional T-shirt pattern consists of a front and back joined at the shoulder and sides. Despite the use of these conventional patterns, they gave a clear and identifiable place to begin the design process.

Woven fabrics produced on a loom are almost always rectangular. I am accustomed to working with this limitation due to my experience with zero waste pattern cutting, however, the possibility of creating space in the weave was not a technique I had been able to explore before. I stacked the pattern pieces *into* the textile's layers (see figure 2), woven so that when cut and separated, can create a shaped 2D pattern from a rectangular 2D textile[11]. The front and back are overlapped at the shoulder seam as shown in figure 2.1, and the sleeve pattern is placed overlapping in the same area so that a maximum of three layers[12] is needed in the woven structure. Due to the use of 3D software, I could easily see the impact of the placement of these pattern pieces on the expression of the 3D design. The placement was simultaneously guided by the resulting expression, the requirement that all areas of the weave be 'used' for the garment[13] and the technical considerations for weaving concerning thread density. In short, through technology I am able to design the macro structure of the textile, garment form and surface expression at the same time – no one single element consistently overrides the others.

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[11] Often in the field tests discussed earlier in the paper, I wanted to be able to 'find' or make space beyond what the flat fabric could provide, and in this technique, I discovered I am able to.

[12] This self-imposed 3 layer maximum was determined based on the relatively low warp density I had available to me. The warp density of the cotton industrial jacquard loom used for these samples is 33 ends (warp threads) per cm, so when divided into three layers each layer would have a maximum of 11 ends per cm, which is considered very low for apparel textiles. With a higher density warp more layers would be possible.

[13] So none would be cut off and discarded, as is required in zero waste design

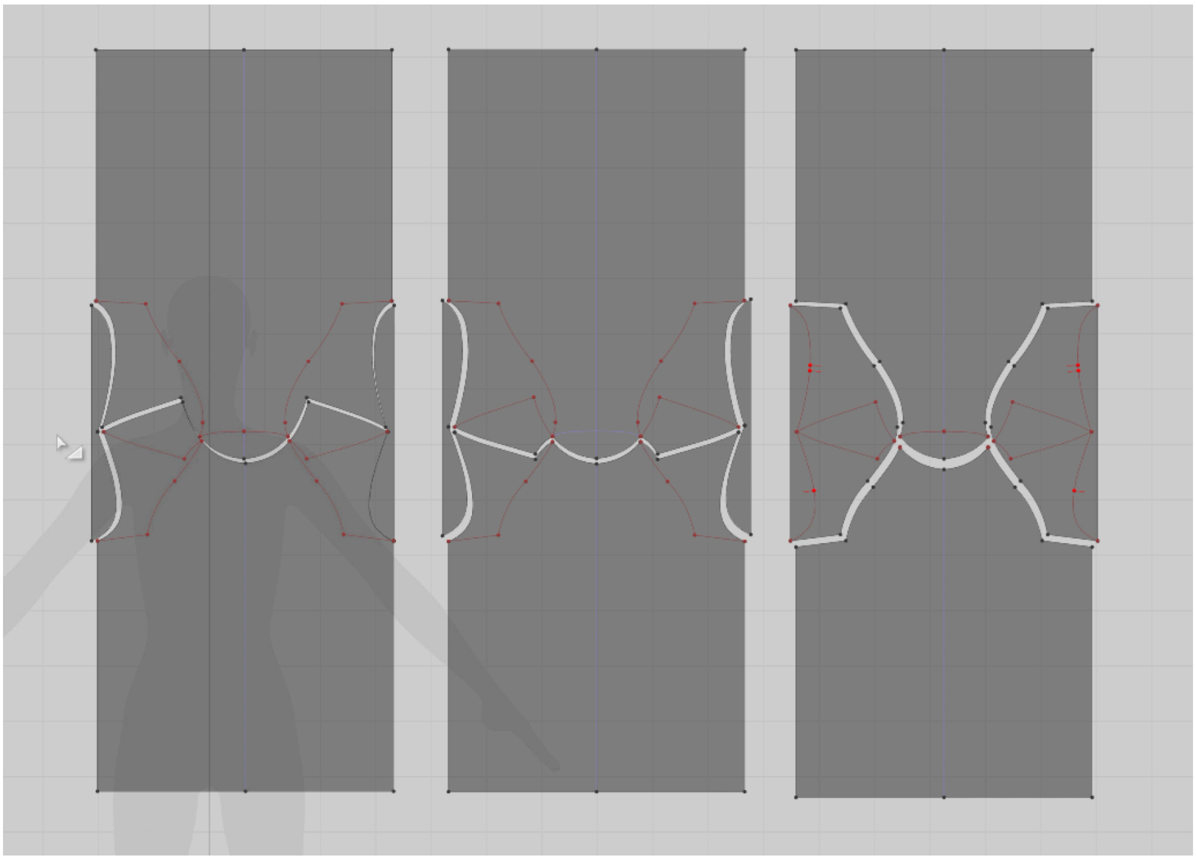

Figure 2. T-shirt Iteration Two development showing three layers that make the weave when separate and not stacked for weaving. Red lines show overlapping conventional t-shirt patterns.

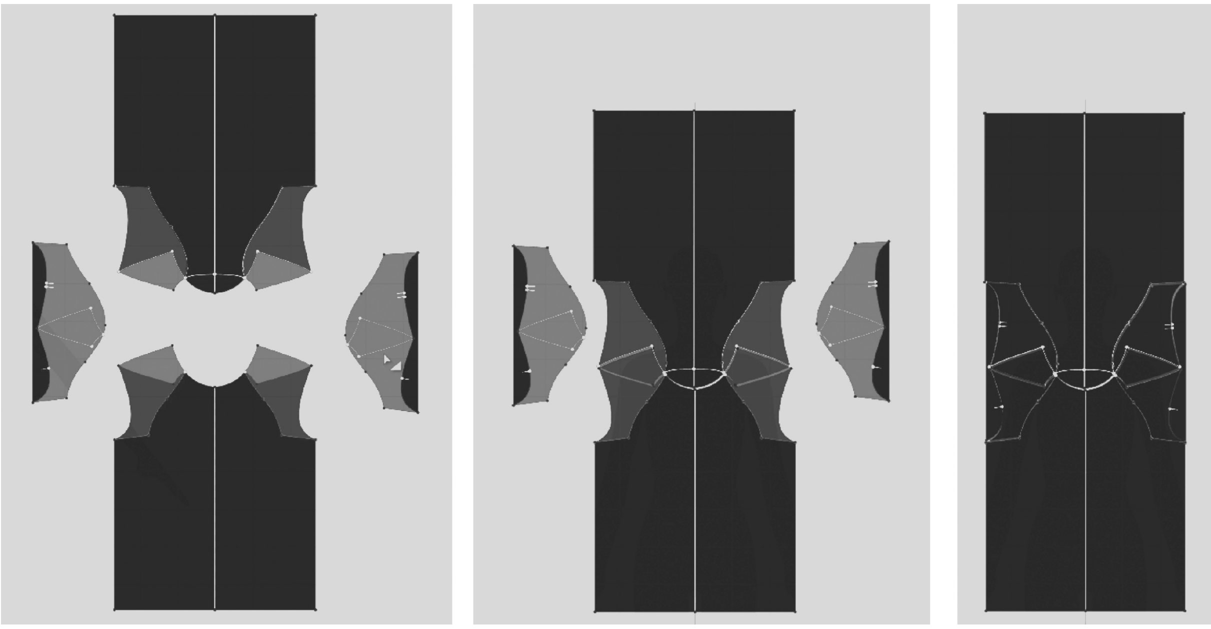

Figure 2.1. T-shirt Iteration Two development showing stacking of the three overlapping layers. Left to right: T-shirt pattern shapes (front back and two sleeves); Front and back overlapped; Front, back and sleeves overlapped (this is how the T-shirt is woven on the loom.

The three-layer 'stacked' pattern was exported from CLO3D as a PDF and opened Illustrator. In Illustrator the three layers of patterns are sandwiched to produce a single layer, colour-coded 'map' of weave structures or 'bindings'. The bindings used in the research so far are simple and fall into three categories, fill, edge and cut, and all determine the relationship between the three layers. There are 16 possible binding types for these T-shirts, so there are 16 colours: this constructs the map of bindings (Figure 3), which determines both 2D space (woven) and 3D potential (form).

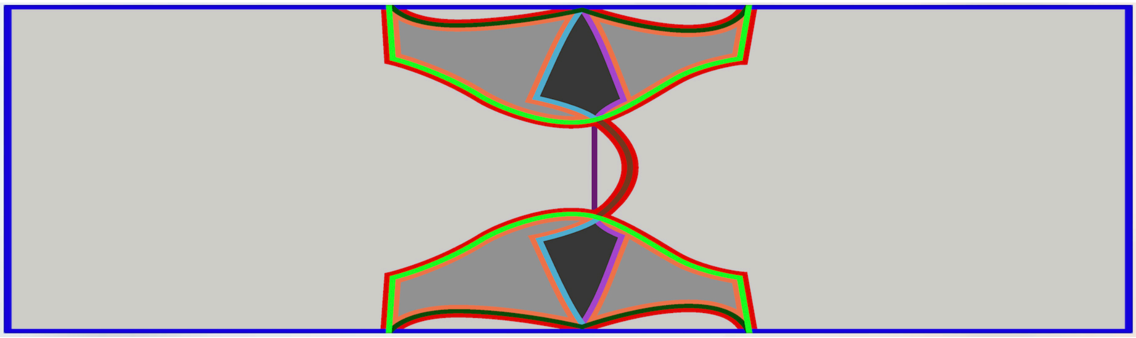

Figure 3. T-shirt Iteration One, map of bindings. Each colour defines an area with a specific weave structure and therefore a relationship to the other layers above and below. File is elongated to account for weft density.

The impact of repeat size, and weft density on the scale of the garment is important. The loom used has a 40cm repeat, and the same design must be repeated four times across the width of the textile, making a 160cm wide cloth. When I designed the T-shirt, I used a standard T-shirt pattern which is 55,5cm wide, so the repeat would ideally be this size. In order to test the concept as simply as possible, I shrunk the pattern to be 40cm wide in Illustrator, acknowledging this will result in a T-shirt with a maximum circumference of about 76cm[14] – a size which will likely only fit a child. The impact of weft density on the scale of the garment also needs to be addressed. For example, if I weave the T-shirt at a density of 50 threads per cm, then the file is scaled to ensure it is the correct length to translate pixel dimensions (which are square) to thread density (which is not). If I halve the thread density to 25 pics per cm without changing the file's vertical scale, I will end up with a T-shirt twice as long.

The correctly scaled map of bindings is then exported to Photoshop to translate to pixels instead of vectors and check that the total pixel dimensions align with the warp density. From Photoshop I export as a PSD file to ScotWeave where I can assign specific bindings to the map colours and generate the code which the digital jacquard loom can read. The textile is woven using a different coloured yarn for each of the three layers in order to better visualise the process[15]. After weaving, I carefully cut the layers separate from each other using the floats as cut guides (Figure 4) and constructed the T-shirt conventionally. The resulting T-shirt requires the same number of sewing seams as a conventional T-shirt and has the same silhouette (Figure 5); however, it is zero waste. It becomes clear that whereas for 'conventional' zero waste you measure yield and waste by area, with this hybrid zero waste method you need to measure yield by weight of yarn used. The T-shirt only produces a small amount of yarn waste in the auxiliary selvedge (assuming you cut it off). The surface expression of the T-shirt textile is a direct result of the process used to design and produce it and makes explicit the simultaneous design process that is undertaken[16].

[14] 40cm front and 40cm wide back, minus seam allowances
[15] Top layer of the weft yarns is white, while the middle layer is grey and bottom is black. All yarns are 100% cotton.
[16] If all the weft yarns used were the same colour visual difference of the textile would be significantly reduced.

Figure 4. T-shirt iteration one, sleeve layer cut from body. Transparency of sleeve is caused by the low weft and warp density of the loom.

Figure 5. T-shirt Iteration One is sewn using a standard t-shirt construction sequence, side seams, shoulder seams and armhole. Auxiliary selvedge shown as fringe on left side, this can be removed.

6.2 T-shirt Iteration Two – sliding layers

T-shirt Iteration Two was in response to the limitation of a 40cm loom repeat. To change the width of the T-shirt within a fixed repeat I utilised the 'stacking' layers method across the width of the body. The allowed me to 'slide' the layers further apart across the horizontal plane (Figure 6). In Clo3D I first divided the basic T-shirt front and back patterns vertically into panels and then overlapped these to fit inside the 40cm wide repeat (Figure 7). This resulted in a zero waste T-shirt (Figure 8) which requires more sewing than a conventional T-shirt, but which fits an adult and allows this design to be graded up to any size[17] where the circumference is less than about 230cm[18].

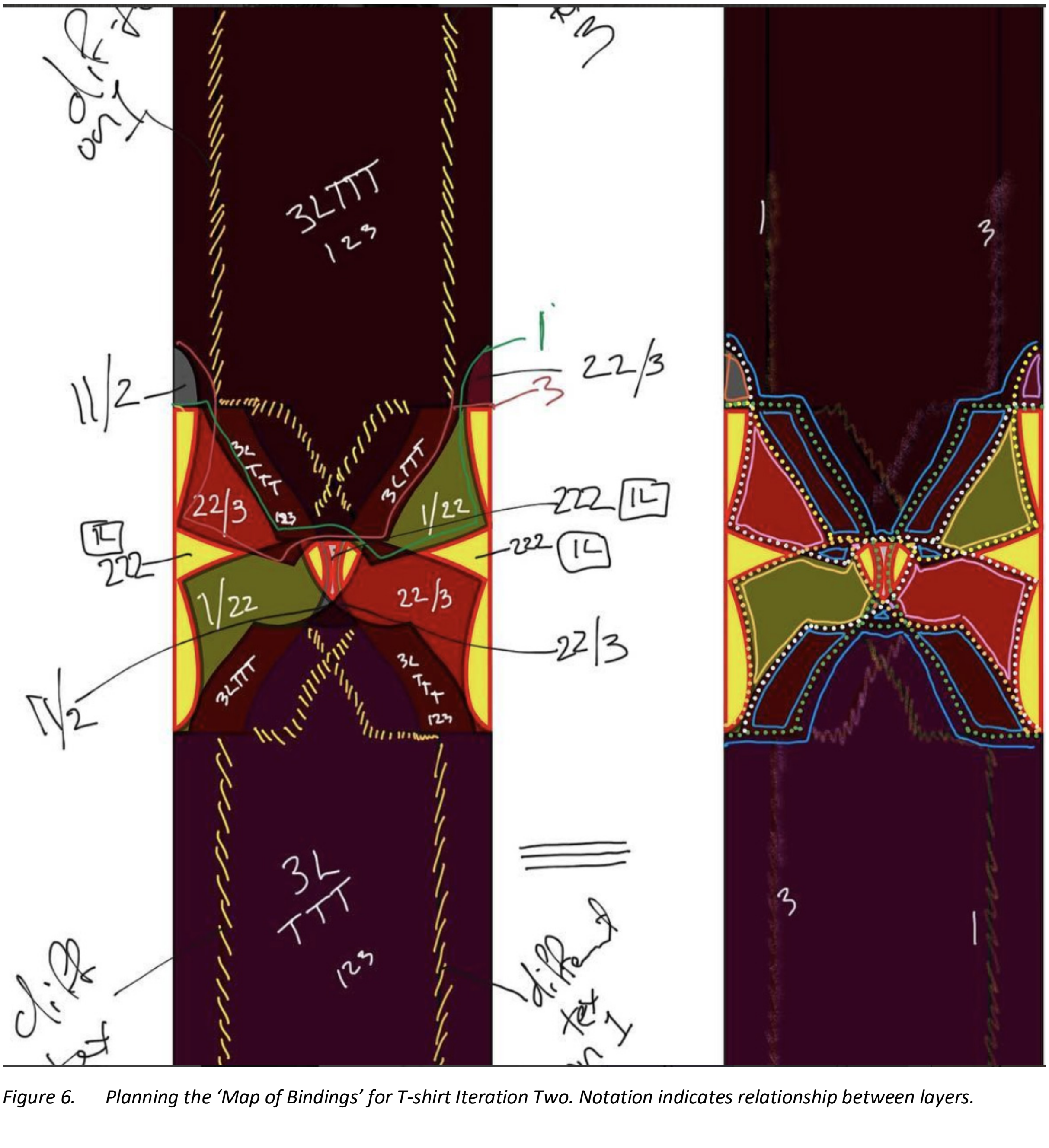

Figure 6. Planning the 'Map of Bindings' for T-shirt Iteration Two. Notation indicates relationship between layers.

[17] The resulting designs in different sizes will have visual differences to each other, a concept already proposed by Rissanen (2013) as a method to address grading problems within zero waste design.
[18] 40cm front, and 40cm wide back, multiplied by three layers, minus seam allowances

Figure 7. T-shirt Iteration Two on the loom as it is being woven, 40cm wide repeat shown

Figure 8. T-shirt Iteration Two, once cut and sewn as a 'Half' sample, actual design would be full length. Different weave structures are visible particularly on the sleeves, which are a result of the design process. More extensive sewing is required to form the outcomes generated from the sliding method.

6.3 T-shirt Iteration Three – expanding layers

I next aimed to find a method of reducing the construction required to less than for a conventional T-shirt. In Clo3D I noticed that what I thought of as 'sliding' appeared more like 'unfolding'. So using paper models first, and then moving to Clo3D (Figure 9), I conceived of a stitch-less method of embedded form making where the woven cloth has the form embedded and released when cut. Initially the 3D form of a T-shirt is flattened by cutting the side seams open so the form of the T-shirt can be flattened and then folded to conform to a rectangle for weaving. The design of the original T-shirt is modified throughout this process in order to utilise all of the available the 2D space of the textile. By designing the 3D-Tshirt-potential of the 2D textile, design elements such as the shoulder slope and armhole shape are embedded into the weave, which then through cutting, the T-shirt form is realised, with final form construction requiring only two side seams [19].

Figure 9. T-shirt iteration Three, showing expanding layers at shoulder and armhole (in light and dark grey) to enable fit and ease of movement. Only the side seams are needed to be sewn in this t-shirt, in contrast to the usual side, shoulder and armhole seams in a conventional garment..

7. Insights and Conclusion

7.1 Pattern cutting as Flattening

All pattern cutting for cut and sew garments is a process of flattening the 3D form. Zero waste design as an experimental design practice also explores what is possible when we three-dimensionally form the flat textile. The converse of utilising origami to turn flat sheets into curved geometries (Callens, S. J. P., and Zadpoor, A. A. 2018), this hybrid zero waste research takes curved geometries (in this case T'shirts) and 'flattens' them into weave-able structures. It is an iterative 3D – 2D – 2D – 2D – 3D process (see figure 10) that transforms the outcome at every step, and flattens 3D form *into* an apparently 2D textile. I am defining the interstitial space-potential in textiles – treating the textile as 3D potential.

[19] If the T-shirt was woven in 6 layers it would not require any stitching at all.

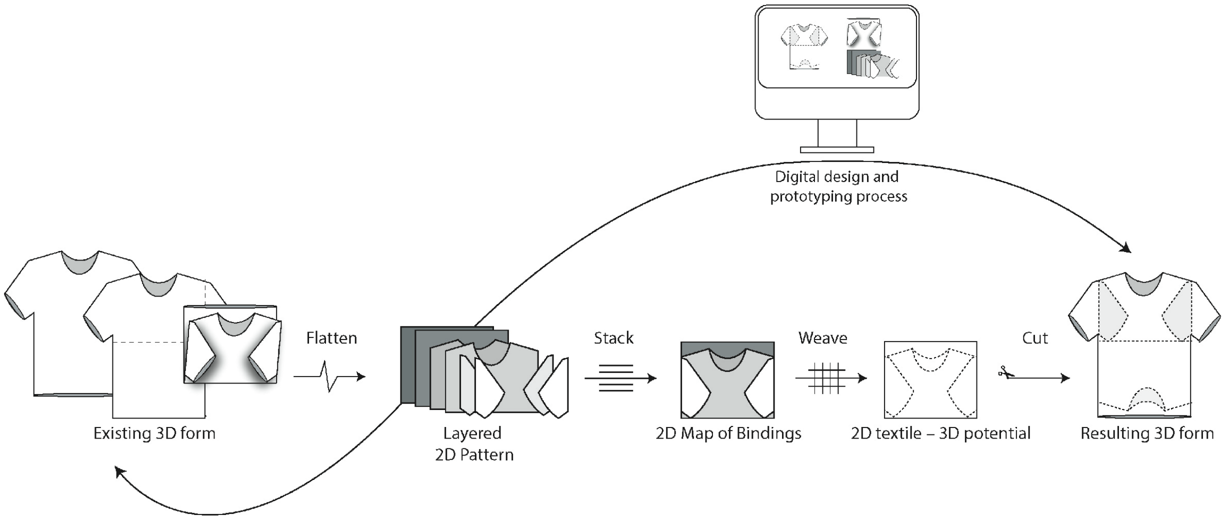

Figure 10. Proposed design model demonstrates 3D – 2D – 2D – 2D – 3D relationship, interpretation and impact. The design process is supported by a supplementary digital design and prototyping process allowing the development out complex 3D outcomes while simultaneously developing the required 2D structure.

This research presents outcomes for the human body, but they are only one set of examples. Of course this approach can be applied to many different 3D applications where we utilise woven textiles: interior furnishing (curtains and screens), furniture, spatial design, agricultural furnishings (climate screens), construction design (weave 3D building structures into flat cloth), or expanding forms used in science and technology such as folding robotics[20].

7.2 Technology – how it designs us as we design it.

It is not only the direction and method of flattening that informs and directs the expression of the form, but it is also guided by the technology utilised in its manufacture. In the case of the examples presented here the stacking, sliding and expanding techniques used directly impact on the expression of the textile surface. As the designer, I have to choose the areas where the emergence of the form should dominate the desire for a particular surface texture, or when texture and weight are more important. The direction and method the form is flattened, then further informs the textile design and resulting garment form. The design of these textile-forms is a dance between form, function and surface expression[21] which is constrained – and enabled – by the technology we use to design and produce them.

7.3 Future making for garment making

Through this research, I make examples that show how things are made while questioning why and in what context. Dilnot (in Yelevich and Adams, 2014, p. 196) argues for an ethical approach to future making asking – when designing and future building Simons (1969) "preferred" future, how do we define the ethics of this? Tonkinwise (in Yelevich and Adams, 2014) advocates for a process of intentionally designing out the things we do not need or that don't serve us – "the very active act of unmaking aspects of our locked-in world – designing things out of existence" (p. 198). In making

[20] There are other advantages – such as the ability to shipping as flat (flat pack furniture) or on a roll. The potential for the 3D forms to easily collapse back down to its flat 2D woven form can also be exploited in other areas – curtains, screens, smart textiles or even folding robotics.

[21] However at this stage many of these limitations are caused by the technology I currently have available for sampling and would radically change with changes such as utilising a higher density loom and variable yarn thickness/behaviour.

these examples it becomes clear I am not only designing something, but I am also proposing we must "design away" some of the things we already have and do.

The examples and theory explorations presented here seem situated between two seemingly opposing viewpoints within the scholarly sustainable fashion community, viewpoints which inevitably mirror the debate around wider ideas of sustainability. On the one hand, we idealise technological improvements, while we are seemingly resigned to the massive scale of the industry. There dominates a low cost, high science model of 'change without change', where industry hopes that with technological advancement in areas such as fibre recycling we can continue with the remainder of the industry as it currently operates. While on the other hand, we glorify small-scale, handcrafted garments and practices, where time and money intensive practices present a model of 'change by changing back' to how we used to do things. When invented in the early 1800s the jacquard loom was considered disruptive technology, so much so that many looms were destroyed by the workers they replaced, while the looms inventor was attacked. Eventually, society accepted the jacquard loom because of the positive change it brought to the industry. My research is 'future-making' – proposing artifacts which might exist as a result of a kind of 'high-tech cottage industry' – which suggest ways of being for designers, manufacturers and users alike.

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