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Methods for Designing Woven Textile-forms: Examples from a pedagogical textile design workshop

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When designing Woven Textile-forms, both the 3D object and the textile it is composed of need to be developed simultaneously, a process requiring an adaptation of currently established methods from both textile and fashion design. This paper provides an overview of existing examples for woven form-construction approaches through the lens of fabric (non-)rectangularity. It subsequently presents the method of flattening a 3D form into a weaveable 2D format, and the alternative weaving methods of Modular Weaving, Non-binary Weaving and Multi-selvedge Weaving destined at constructing non-rectangular seamless Woven Textile-forms. It further describes a range of associated prototyping and visualisation techniques including Maps of Bindings, paper models, Thread Maps and miniature nail looms. These are destined at helping textile designers in conceiving textiles in the shape of the final object instead of flat rectangular surfaces, and at providing woven form designers with alternatives to conventional cut-and-assemble approaches, thus creating new grounds for cooperation between both disciplines. The utility of these methods and techniques was tested during a workshop for textile design Masters' students at École nationale supérieure des Arts Décoratifs in Paris, the results of which show that the integration of form-thinking into the textile design process is possible and generates new opportunities for form-making beyond cut-and-assemble.

Keywords: Woven Textile-forms, weaving, design methodology, textile design

1. Introduction

Woven textile designers are most often trained to conceive rectangular and planar fabrics that form designers (i.e. fashion or object designers) can subsequently cut into pattern pieces and assemble into textile objects primarily by means of sewing. Though wasteful (Abernathy et al., 1999; Cooklin, 1997), this Cut and Sew (C&S) method is often taken for granted and creates a separation between textile-making and form-making (Drews, 2019). Yet it is precisely by merging these two practices that

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alternative methods can be developed. Woven Textile-forms (WTfs) can especially provide an interdisciplinary base for renegotiating the conventional relationships between weaving, cutting and sewing and for finding alternative assembly methods. WTfs are complex three-dimensional textile objects whose form and fabric are designed and constructed at the same time and in interdependence with each other (McQuillan, 2020b). While the development of WTfs remains at an experimental level, knitted form-making has become a commercially established[1] alternative to C&S over the last two decades, since its seamless construction method bears e.g. the potential to reduce waste, production steps and transport requirements and provides an improved wearing comfort and absence of breaking points at the seams (Conti, 2019; Giglio et al., 2022; Nawaz & Nayak, 2015).

The design process for Wtfs entails a hybridisation of the disciplines of textile and garment or object design and can therefore be considered similar to a Simultaneous Design approach[2] (Townsend, 2003) - except that it is not only limited to body relations of textiles and form. Consequently, it requires a redevelopment and adaptation of established methods and techniques such as e.g. sampling and creating lifting plans and weave drafts in textile design (Forst, 2022; Redmore, 2011) and pattern-making and toileing in fashion design (McQuillan, 2020a; Rissanen, 2007). This need for new methods reflects the complexified design process prior to weaving resulting from the combination of production steps during the simultaneous construction of textile and form.

2. Existing woven form construction approaches

The arrangement of warp and weft yarns in biaxial weaving lends itself most easily to rectangular and planar weaving and most woven textiles are designed this way. If 3D form is a desired application of such conventionally woven textiles, the planar and rectangular fabric must be cut and sewn, often resulting in problems relating to pre-consumer waste (Rissanen, 2013; Rissanen & McQuillan, 2016; Runnel et al., 2017) due to the mismatch between pattern shapes and the rectangular shape of the fabric, and the manual labour required when sewing.

Over time, an increasing division between the practices of woven textile design and form design has been observed (Drews, 2019). However, this separation is less clear when looking outside of conventional woven textile and C&S design as practised in the Western industrial context, since the design of woven textiles with a particular final form in mind is demonstrated in examples throughout history and in many parts of the world. Next, we present examples grouped as rectangular or non-rectangular approaches for weaving form, and within each show the varying degrees of post-weaving intervention required to produce 3D form. In contrast to C&S, all these examples require a shift of the design of form from a post-weaving process, to one that is integrated within the design of the woven textile itself and demonstrate the range of approaches explored so far by scholars, designers and craftspeople.

2.1. Rectangular weaving for form

Within rectangular biaxial weaving, a simultaneous consideration of textile and form can be observed in examples such as the sari, where the positioning of motif sections on the woven rectangular textile is guided by the form the sari takes when worn (Kawlra, 2005). Rectangular woven textiles

1 Companies such as Nike and Adidas have integrated seamless knitting into their product range, thus reducing costs for materials and manual labour and creating the potential for a relocation of automated production lines closer to principal consumer markets (Euchner, 2015; Kaziur et al., 2022; Liu, 2020).

2 Townsend (2003) developed this concept for printed Lycra® garments, where the motif, the fabric behaviour and the body wearing the garment are considered interdependently during the design process.

may be designed to include slits for the head or limbs, such as in poncho examples (Burnham, 1973), or can be designed to produce a specific form by embedding the 2D patterns within the rectangular textiles, which are later cut and assembled to construct the form (Brunnhuber, n.d.; Habert, 1978; Miyake & Fujiwara, 2001; Piper, 2019). When we understand the potential of weaving to explore 3D interlacement in multilayer weaving, 3D forms can be increasingly constructed on the loom, thereby reducing or eliminating the manual labour required after weaving. These are known as WTfs (McQuillan, 2020b), and in the context of clothing as 3D woven garments (Audren, n.d., Vroom, 2022), or Composite Garment Weaving (Piper, 2019; Piper & Townsend, 2015). Some WTfs still require some cutting and sewing to realise their complete intended form (Dekhla, 2018; McQuillan, 2019; Piper, 2019), while others require cutting but no sewing (Dekhla, 2018; Harvey et al., 2019; Shi et al., 2022), or no post-weaving intervention at all (Drews, 2019; Norgate & Bennett, 1976; Braunius as described in Roth, 1918).

2.2. Non-rectangular weaving for form

If we consider that it is possible to generate non-rectangular shapes using biaxial interlacement of the warp and weft, the possibilities expand further. Within non-rectangular biaxial weaving, we can see evidence of simultaneous consideration of textile and form in examples such as the ancient Roman toga or the Moroccan *akhnif*, where the semi-circular shape of the planar woven textile is guided by the form the garment takes when worn (Granger-Taylor, 1982; Naji, 2021). Alternatively, non-rectangular 2D patterns are woven to shape and subsequently assembled by sewing (Colburn et al., n.d.), and may be additionally engineered for specific behaviour or appearances (Beck et al., 2014; Wagner et al., 2022). Elsewhere, elements such as sleeves are woven to shape and then attached to the rest of the garment by sewing (Manonik as described in McQuillan, 2020b). In other cases, specifically adapted looms and/or weaving techniques allow for the construction of integrally woven non-rectangular forms that require few (Visser, 2023) or no post-loom interventions (Drews, in press; Knoll, 2022; Martin et al., 2020; Steinmetz, n.d.).

2.3. Form-thinking for non-rectangular weaving

In many cases, the development of weaving for form creation is approached from a textile designer's or weaver's viewpoint (Habert, 1978; Piper, 2019). This leads to a dominance of planar and rectangle-based perspectives on form as this is the tradition that woven textile designers are most often trained in. The lack of form training within textile design results in a possible missed opportunity for the development of alternative construction approaches for textile-based objects. In tandem, C&S is rarely challenged in fashion design, and few students of fashion (or form-design in general) have a deep, if any, education in weave theory or practice. In this research we wanted to further develop our methods for form-thinking and explore their utility for textile design students asked to conceive WTfs.

3. Methodology and techniques for designing zero waste and seamless WTfs

Juri-Apollo Drews has a textile design background and developed methods for non-rectangular weaving which can eliminate the need for post-loom construction of form. Holly McQuillan has a fashion design and zero waste design background and has developed design methods for producing form on the loom. Juri-Apollo Drews attended a workshop on WTfs held by Holly McQuillan and Milou Voorwinden at TU Delft in 2022. Here, we saw the potential of combining our approaches by developing a common workshop teaching our complementary methods to textile design students in order to evaluate their potential for persons taught in conventional weaving.

The methods and techniques presented in the following are intended to help textile designers in considering the fabric in terms of the three-dimensional shape of the final object, while also helping e.g. fashion designers to reflect on the fabric and its precise construction on a deeper level than they might be used to. These methods therefore aim at making the intersections between both disciplines visible and understandable and can prepare new opportunities for communication and cooperation between the two fields. They do not represent a linear protocol but are used simultaneously during the design process in order to gradually negotiate the relationships between fabric, 3D shape and production tools.

3.1. Off-loom preparation for designing and making WTfs

In order to be woven, the desired 3D form needs to be translated into a 2D format. In C&S, this is achieved via a flattening-out process (unwrapping form into 2D planar shapes), however when weaving Textile-forms (Tfs), a flattening-into process (folding an existing 3D form into a flattened one that can be woven on a loom) is required in order to eliminate sewing (McQuillan, 2020b). This flattening process includes folding of existing forms (Figure 1a), paper modelling (Figure 1b), and toileing. It translates 3D form (Figure 1c), into a 2D format with an associated cross sectional understanding of weaving (Figure 1d) which builds on double weave/cloth methods where the warp and weft can be divided into multiple layers superimposed and woven simultaneously. The Map of Bindings (MoB) communicates where this is done across the 2D plane (Figure 1e), the layer notation (Figure 1f) articulates how the warp and weft are divided into these layers. For jacquard WTfs this information is then used to make a draft or program a weave file[3].

3.2. Methods and additional requirements for non-rectangular and seamless WTfs

In order to produce flattened three-dimensional forms seamlessly, Juri-Apollo Drews has reconfigured conventional shaft looms and has developed alternative hand weaving methods permitting the construction of complex multi-layered three-dimensional Tfs and garment prototypes such as e.g. trousers (Figure 2), which are entirely woven and require no cutting or sewing once off the loom. These include:

- *Modular Weaving* (MW), through which different woven and/or knitted modules can be seamlessly connected to each other during the weaving process through fringed weft fibres left unwoven at the module's edges,
- *Non-binary Weaving* (NbW), allowing to produce slanted or curved selvedges and non-rectangular textiles through a reorientation of warp and weft fibres during the weaving process, and
- *Multi-selvedge Weaving* (MsW), allowing to produce non-rectangular textile shapes without fringes and with one continuous warp thread (Drews, in press).

When used for non-rectangular WTfs, the flattening methods presented in 3.1 are combined with Thread Maps (TMs) (Figure 3) indicating the trajectory of the individual threads and how these connect into each adjacent layer and any additional yarn systems. TMs can represent the changing di-

3 For a comprehensive overview of these processes cf. Buso et al. (2023).

rections of the threads in NbW or the fringes at the edges of modules in MW and are therefore more precise than lifting plans or weave drafts used in conventional rectangular weaving.

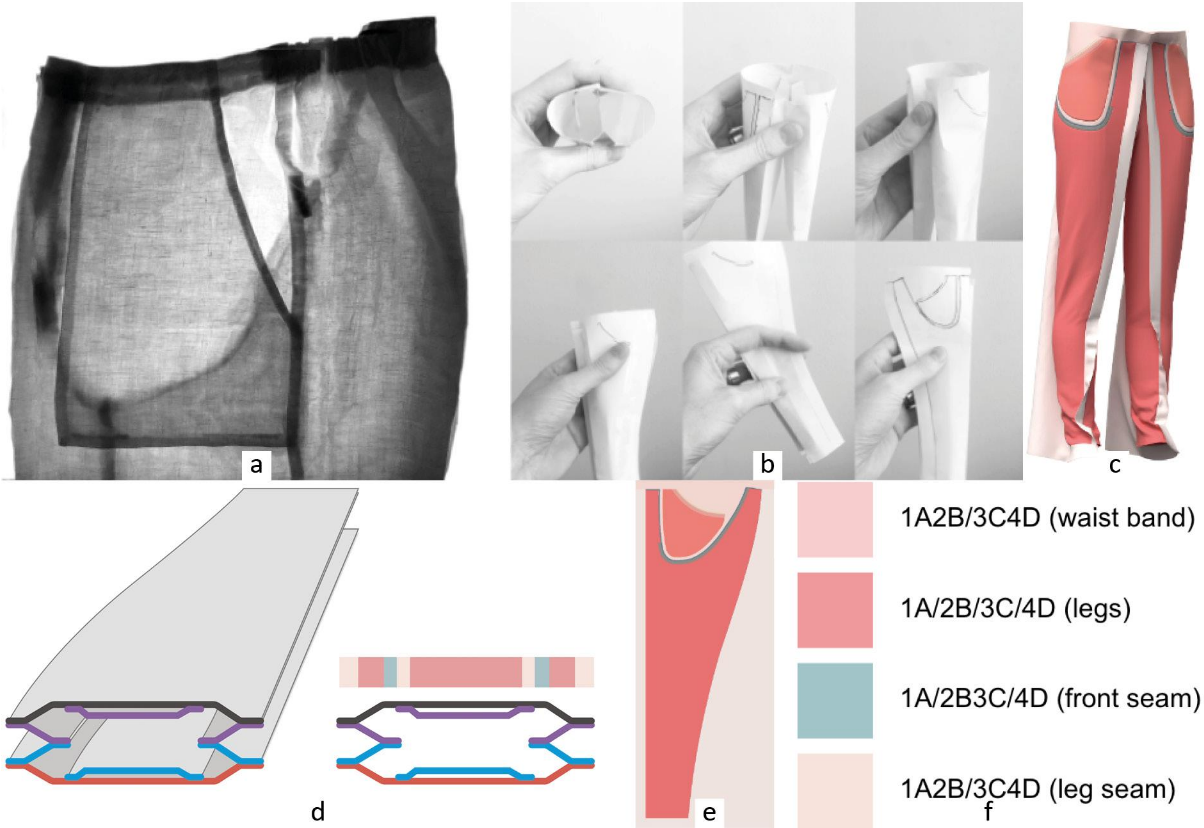


Figure 1. Folding trousers into flattened profile using existing garments (a), using paper models (b) to explore 2D/3D translation, corresponding digital 3D model (c), one cross section of the trousers (d), trouser MoB (e), and technical colours with associated layer notation (f). Images by Holly McQuillan.

Figure 2. Seamlessly woven trouser prototype by Juri-Apollo Drews.

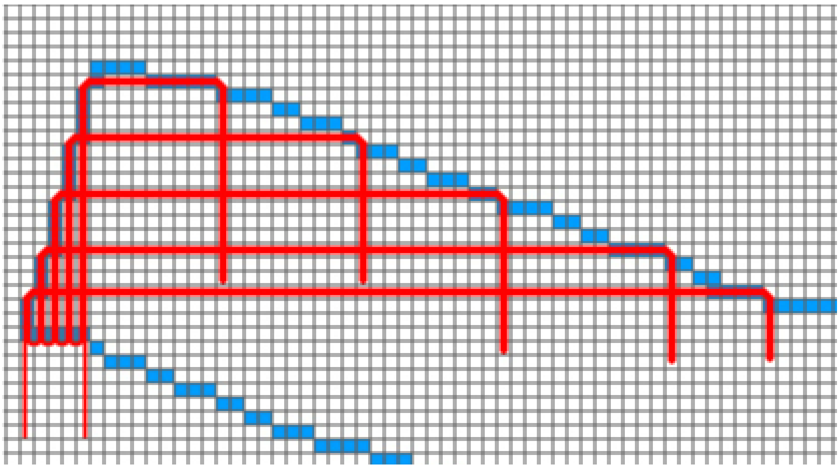


Figure 3. Excerpt from a digital TM highlighting a particular yarn system.

4. Workshop contents and results

The two-week workshop *Non-rectangular Woven Textiles as a Strategy for Zero-waste Design* was co-developed by the authors for seven students of Aurélie Mosse's *Nouveaux Savoir-Faire* course in the context of the master's programme in Textile and Material Design at École nationale supérieure des Arts Décoratifs in Paris in December 2022. Further participants were a fashion design student from PSL University's Mode et Matière master's programme and a textile artist. The aim of this workshop was to introduce conventionally trained textile designers to woven form-thinking through the authors' methods and to reflect on the results obtained from this crossing of approaches.

The students had access to several 24-shaft looms and one semi-automatic jacquard loom, flat-bed knitting machines and a range of natural and synthetic yarns. Table 1 shows the course schedule.

Table 1. Course schedule.

Day	Activity	
1	Morning: introductory presentation	
	Tutorial 1 (Group 1)	Tutorial 2 (Group 2)
2	Tutorial 2 (Group 1)	Tutorial 1 (Group 2)
	Afternoon: discussion, work team formation	
3-5	Concept development, preparation, production	
6	Interim presentation	
7-9	Production	
10	Final presentation (hybrid)	

Rather than producing perfectly finished final pieces, the students were asked to explore Wtf-making experimentally and to document their design and production process, including problems. Their feedback was sought throughout the tutorials, coaching sessions, group presentations, and in writing after the course was completed. We wanted to understand if the methods and techniques taught to them had been useful for concept development and if they had had any wider impact on their understanding of textile design.

4.1. Tutorial 1: Flattening and Designing for WTfs

The lack of cohesive digital workflow tools that can support form-thinking for woven textile design means that in the workshop analogue processes were combined with existing digital software (Mc-

Quillan, 2020a). Table 2 shows the range of tools[4] that can be used to achieve outcomes from conceptual understanding of WTf, the generation and verification of a flattened design, MoB generation and processing, and its use in the jacquard design process. The workflow is iterative, and the utility of the tools for transmodal communication means their use is evident across multiple outcomes.

Table 2. Overview of the pedagogical tools used in Tutorial 1, and a description, including the purpose, and outcome for each. A darker tone indicates higher relevance of tools in development of outcome.

Tools introduced in workshop	Purpose	Outcome			
		Concept	Flattened design	MoB	Jacquard design
Visual and oral presentations	Images of WTfs, basic weave theory and zero waste strategies to communicate fundamental concepts of WTf.				
2, 3 and 4 layer WTf samples and garments	Woven samples demonstrate possibilities of approach and show impacts of multiple layers and yarn and weave structures on density/aesthetics.				
Existing garments folded and arranged to explore 2D possibilities	Existing garments (from wardrobe or made specifically for the desired form) aid in comprehension flattening known/desired forms by folding. Can be used for the rapid ideations of possible flattening options.				
C&S toiles made of layers of textiles cut and sewn to make resulting 3D form	Aids in the conceptual understanding of 2D/3D relations, while physically demonstrating layer relations (connections/separations). Also used to verify flattened design in textile format, at scale of the body.				
3D software (CLO3D) showing 2D layers and resulting 3D form	Conceptual understanding of 2D/3D relations, generate flattened designs (including MoB), verify flattened design in (digital) textile.				
Multi-layered coloured paper models	Provides conceptual understanding of 2D/3D relations, demonstrates layer relations in hands-on, easily accessible form (Figure 4). Can be used to generate a flattened design and for MoB planning (including layer notation).				
Drawn cross sections of warp/weft, layer transitions	Allows exploring layer relations across MoB, and supports understanding of layer notations. Can assist in construction of paper/CLO3D models.				
Layer notation system assigns layer relations to technical colours in MoB	Transmodal communication tool between flattened form (cross sections), MoB and jacquard design. Warp yarns are numbers and wefts are letters, forward slash indicates separation of layers (Figure 1f).				
Vector (Illustrator) and Pixel (Photoshop) software used to generate MoB	Generation of accurate MoB based on design and layer notations/relations. In Photoshop indexed colour mode used to ensure technical colours only, and generate image file at pixel/cm resolution and width relative to loom density and total ends.				
Jacquard design software (AdaCAD) for weave programming	Programming of MoBs to generate weaveable files. AdaCAD includes "layer annotation" operation enabling implementation of layer notation system.				

4 "Tools" refers to both methods and Intermediary Objects of Design (IODs) here (Bassereau et al., 2015; Papadimitriou & Pellegrin, 2007).

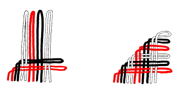
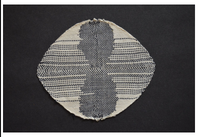
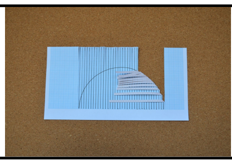
All tools and processes in Table 2 were taught and used in the workshop. The tools within the solid border were utilised with Seamless WTf methods by team 1 and 2 (see section 4.3), and team 3 used the remaining tools in this table to generate their jacquard WTf outcome.

Figure 4. Workshop participant using a provided MoB and three layers of coloured paper (pink, green and black), which are cut and taped together in specific orders to generate a 3-layer 2D/3D paper model of the design.

4.2. Tutorial 2: Designing and Making Seamless WTfs

Table 3 summarises the pedagogical tools used in the second tutorial to introduce the idea that any complex non-rectangular shape can be seamlessly woven. After a presentation of technical drawings, TMs, samples and a toile demonstrating MW, NbW and MsW, the students experimented with these weaving methods themselves on miniature nail looms, which are textile shape-sketching tools developed for this workshop and destined at familiarising persons trained in rectangular weaving with non-rectangular weaving (Figure 5). Subsequently, MW, NbW and MsW were demonstrated on an extended 24-shaft loom. To introduce thread mapping, the students drew a semi-circle on millimetre paper and cut the negative space around the shape into parallel strips representing the warp threads. Folding these perpendicularly visualised the change of direction of the threads in NbW.

Table 3. Overview of the pedagogical tools used in Tutorial 2, and a description, including the purpose, and learning outcome for each. A darker tone indicates higher relevance of tools in development of outcome.

Tools used in workshop	Thumbnail image	Purpose	Learning outcome				
			Concept MW	Concept NbW	Concept MsW	Thread mapping	Loom extension
Visual and oral presentations		Understanding seamless WTfs through TMs and construction sketches of NbW, MW, MsW					
Seamless, non-rectangular WTf samples		Haptic understanding MW, NbW, MsW					
C&S Toile representing locations of MW, NbW, MsW		Understanding MW, NbW, MsW in the context of a concrete garment and as a replacement for C&S					
Miniature nail looms		Hands-on understanding of MW, NbW, MsW (Figure 5); developing ideas for loom extensions (Figure 5)					
Demonstrations of MW, NbW and MsW on extended loom		Understanding non-rectangular weaving on extended looms					
Paper strip model		Introducing thread mapping					

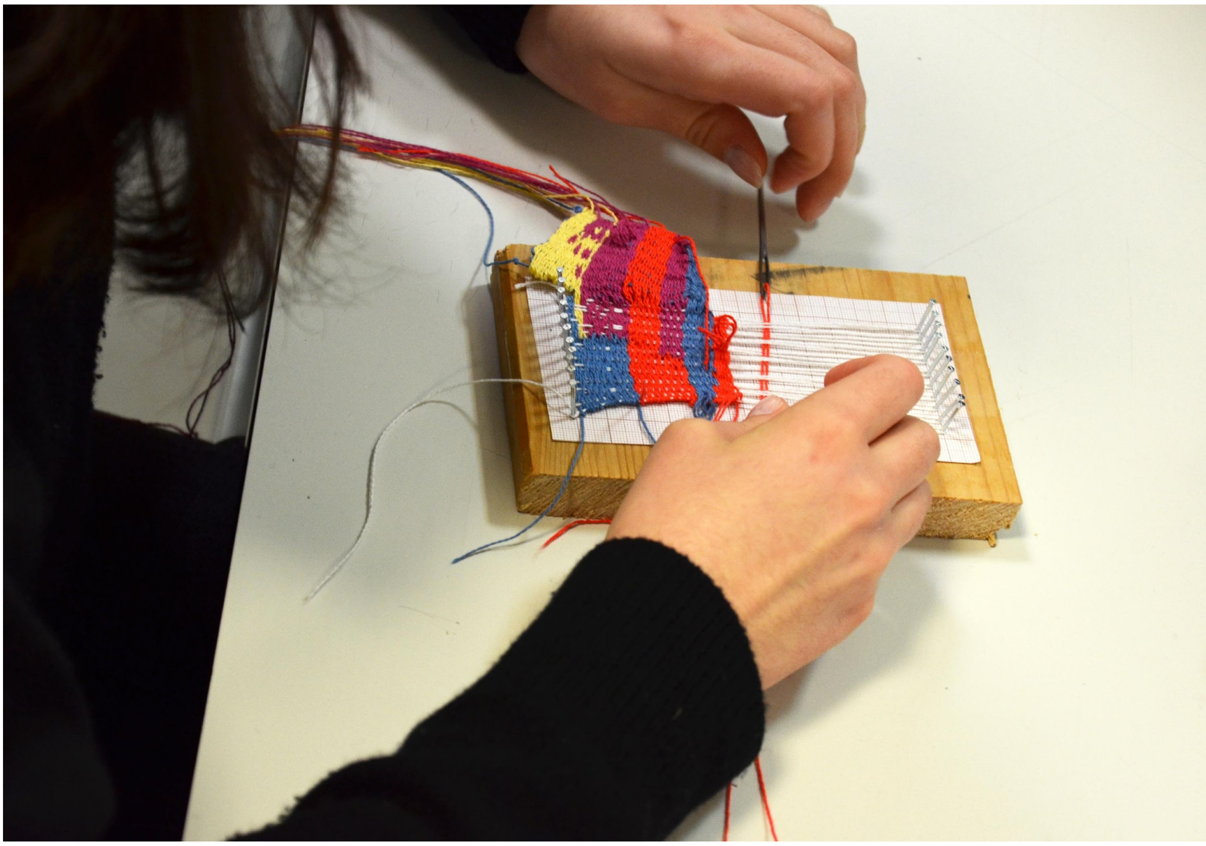


Figure 5. Course participant producing a WTf on a miniature nail loom.

4.3. Workshop results

The students formed three teams and developed prototypes based on form-thinking methods that had inspired them during the initial tutorials. During the design and production processes, they received support from the authors, peers and studio technicians. Figures 6-8 provide insights into the respective design processes.

4.3.1. Team 1: Zero-waste modular headgear

Using the methods of flattening, NbW and MsW, Team 1 developed a prototype for a seamless headgear for migrating in changing climatic conditions. The design consists of a dome-shaped form covering the head, as well as a removable flap (Figure 6a). Six interconnected layers were woven simultaneously that could be unfolded to generate the 3D dome. Due to time constraints and warping problems, the team had to present an unfinished prototype (Figure 6g), whose seamlessly constructed dome shape is nevertheless clearly visible.

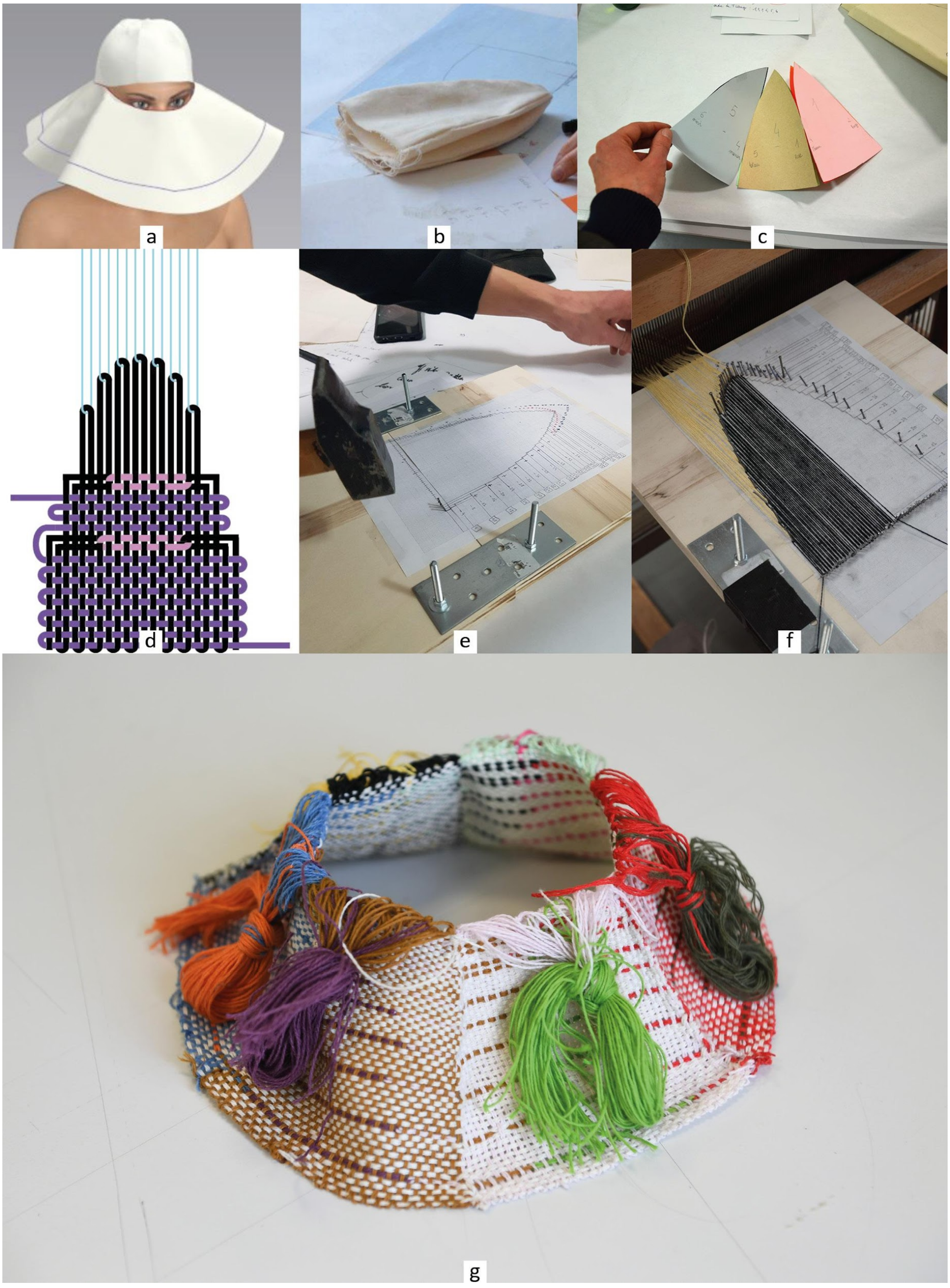


Figure 6. Team 1: Digital CLO3D toile (a), flattened C&S toile consisting of 6 identical tapered modules (b), paper model (c), simplified digital TM (d), manual TM nailed to a wooden plank for warping (e, f), seamless dome shape (unfinished) (g).

4.3.2. Team 2: Saddle cover

Combining the methods of flattening, MW, NbW and MsW, Team 2 designed a prototype for a seamless protective cover for bicycle saddles (Figure 7d) based on the observation that saddle covers assembled by C&S often rip along the seams. It consists of a rigid plain-woven part covering the upper part of the saddle, and a more flexible knitted part that can be wrapped around the lower part of the saddle, thus holding the cover in place. After producing a toile (Figure 7a) and a digital TM (Figure 7b), they constructed the knitted module on a flatbed knitting machine, leaving large fringes at the edges of the piece in preparation for their later insertion into the woven piece. The latter was woven in two layers and could later be unfolded to generate the top of the cover.

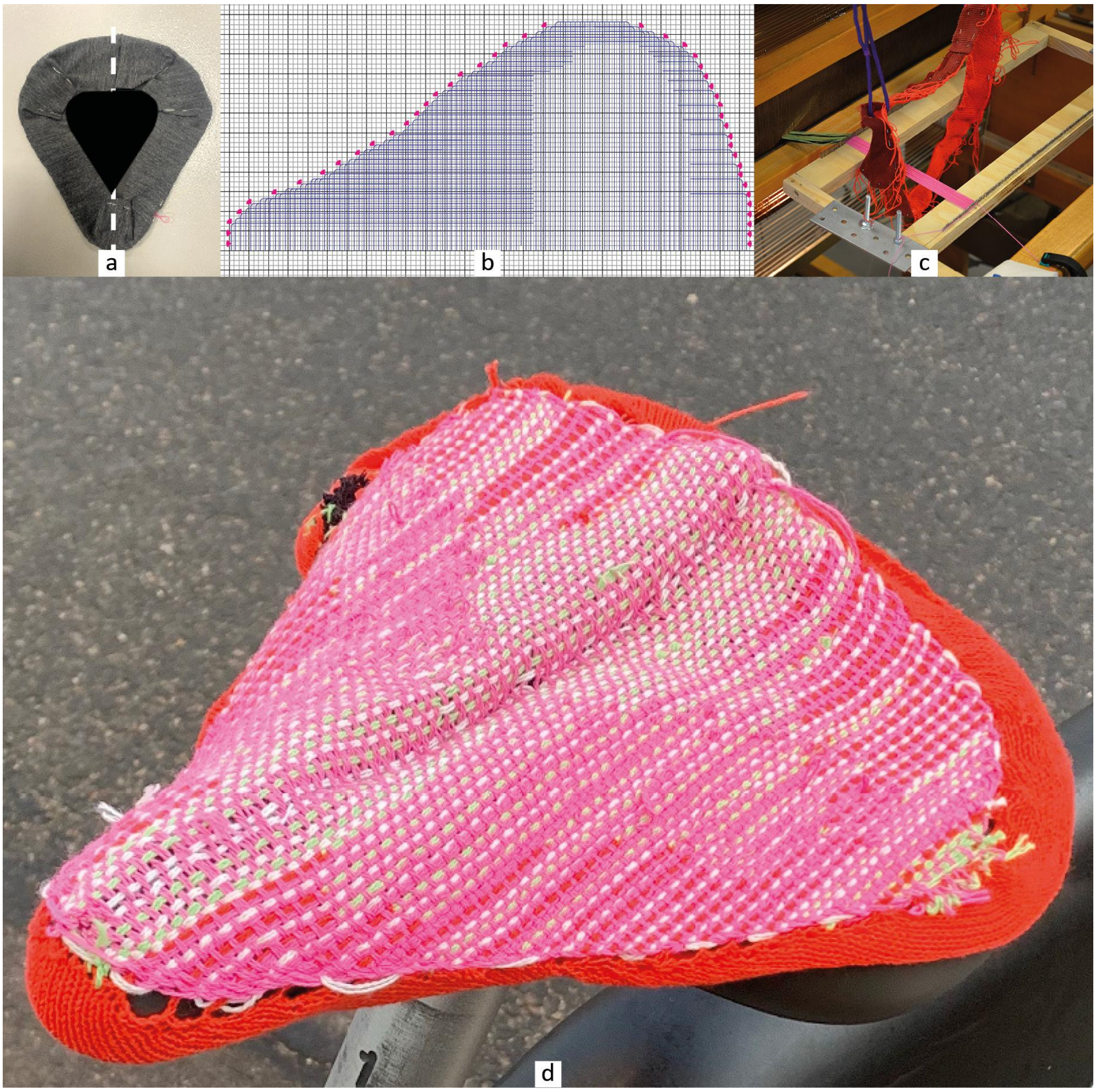


Figure 7. Team 2: Toile from woven (black) and knitted (grey) fabric (a), digital TM of the woven part indicating thread trajectories (blue) and insertion points of threads from knitted module (pink) (b), warping process on extended loom (pink: warp, red: knitted module) (c), finished saddle cover prototype (d).

4.3.3. Team 3: Circular jacquard-woven shapes

Team 3 focused on the experimental development of flattened multi-layered circular shapes. Several circles were nested within each other and woven simultaneously on a semi-automatic jacquard loom. These could unfold and later become e.g. a protection for fragile objects (Figure 8f). The students decided to produce the circular shapes without the methods described in 3.2 by leaving parts of the warp unwoven and cutting out the shapes after weaving, resulting in fringes at the edges (Figure 8e). They braided these into handles for the shape, and realised that when turning the object inside out, this excess material could serve as a pillow filling directly attached to the outer fabric.

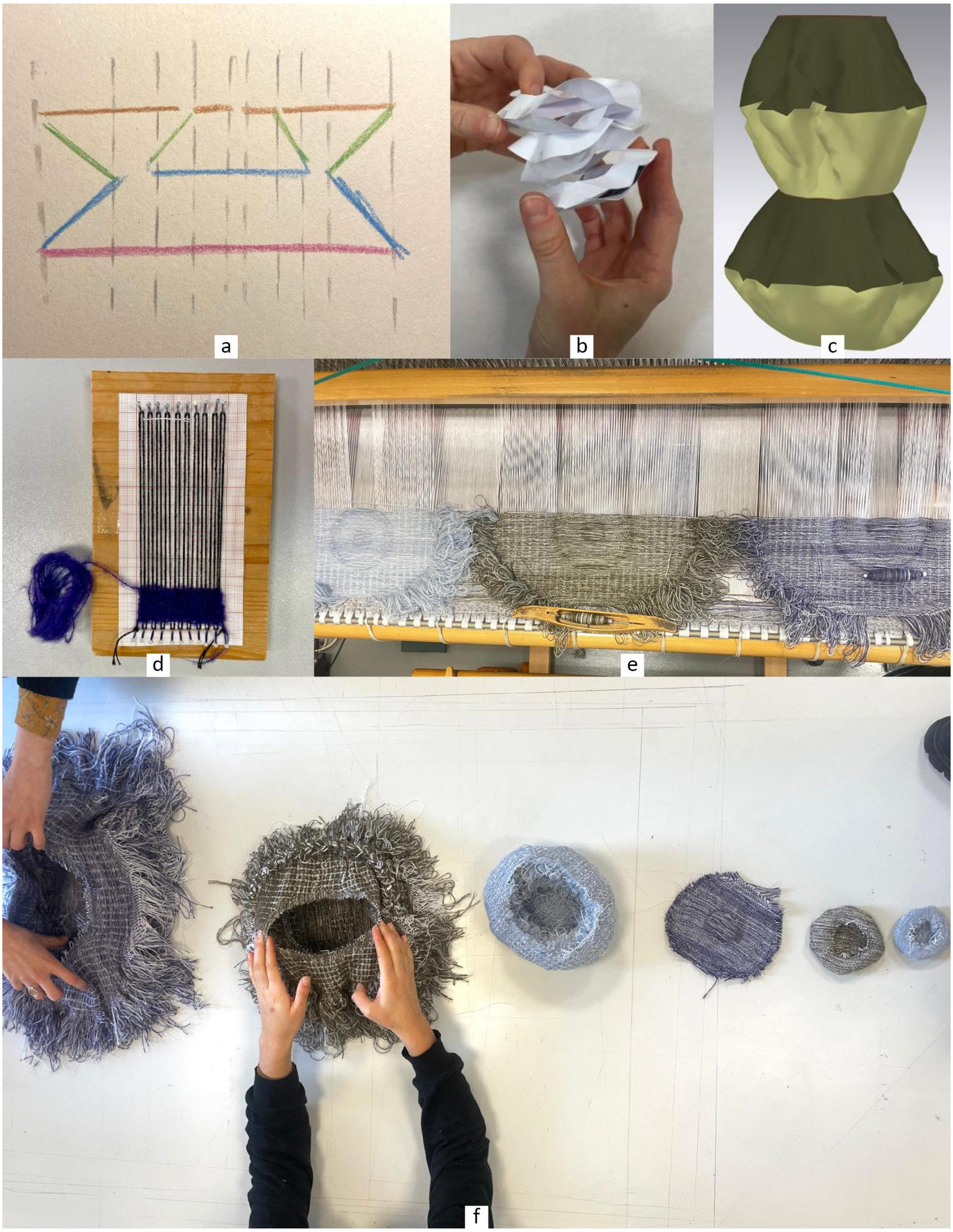


Figure 8. Team 3: Folding concept in cross section (a), paper model (b), digital CLO3D toile (c), yarn tests (d), production on jacquard loom (e), finished circular shapes as they were woven, or turned inside out (f).

5. Reflections

The authors' joint teaching of their complementary methods and techniques provided the textile design students with different possibilities to venture into the field of form-thinking, non-rectangular weaving and loom manipulation. The results show that the students were able to rapidly understand the requirements of these new methods and to integrate form-thinking directly into the textile design process. It added to their understanding of weaving as an alternative to C&S and some participants stated that some tools (e.g. paper models) helped them in understanding the potential embedded three-dimensionality of textiles. Additionally, the nail-looms were recurrently used by the students to rapidly illustrate ideas and discuss them with the team, or to experiment further with MW, NbW and MsW. Beyond the benefits of the application of these tools to make 3D form with textiles, some students expressed that they expanded their understanding of weave theory in general, their comprehension of textiles as a 3D material system, and saw the potential for this to influence their practices beyond Tf-design.

The workshop further showed that instead of teaching sustainable design methods as abstract or theoretical notions, they can be directly embedded into the making-process (McQuillan, 2023). Presenting the students with a diversity of approaches, encouraging them to question established ways of working and to experiment with new methods can create an openness to the idea that alternative ways of form-assembly other than C&S are necessary and possible, and that students can actively contribute to developing them. On a larger level, the integration of form-thinking into textile design could therefore contribute to a less wasteful textile industry, where combined textile and form-making processes could lead to products thought out from the beginning to the end.

In order to achieve this, however, significant systemic changes are necessary in the textile industry, and actors instigating such changes need to be educated. Therefore, form awareness needs to play a larger role in textile education, while textile-thinking and questioning assembly techniques needs to be more deeply established in form education. Future workshops could therefore benefit from a more interdisciplinary setup, in which textile designers develop ideas jointly with e.g. form designers or engineers, whose expertise in digital and analogue 3D modelling, shaping, data analysis, and manufacturing possibilities could provide new insights and solutions. Besides, the development of digital tools simulating the flattening of 3D forms into 2D weaveable or otherwise assemblable formats could further support this dynamic, as well as digital tools simulating the final outcome of such processes.

6. Conclusion

The design process for Woven Textile-forms entails a simultaneous and interdependent reflection of the form, material and assembly of a textile object and requires a shift from form assembly as a post-weaving operation towards an integration of form-thinking into the textile design process. The fabric is constructed in its final 3D form through weaving while avoiding often wasteful form assembly methods such as cut-and-sew. To support textile and form designers' creation of Woven Textile-forms, the paper introduces the methodological approaches of flattening and non-rectangular weaving and several related prototyping and visualisation techniques based on adaptations of existing textile and fashion design methods. These were probed within a pedagogical workshop with textile design master's students. The results show that a larger integration of form-thinking into textile design curricula offers opportunities for developing alternatives to established cut-and-assemble methods, and for stimulating interdisciplinary research on seamless and non-rectangular weaving.

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