Bridging craft and computation through textile-led form-finding

Orynek, Sylwia*[a]; Thomas, Briony[a]; McKay, Alison[a]

[a] University of Leeds, Leeds, United Kingdom
* sdso@leeds.ac.uk

Although the algorithmic nature of textile making has always been recognised and formed the basis of many engineering inventions, textile techniques that proved difficult to automate have remained in the hobby crafts category. Considering the improved flexibility of material fabrication afforded by computation, hand-based methods of thread manipulation should be analysed and disseminated for the sake of interdisciplinary innovation. However, current CAD tools do not support the dynamic and personal nature of craft practices, distorting the creative processes of ideation. In response, this research aims to bridge the gap between craft and computational approaches to form-finding through a hand-based textile practice. This is addressed through a mixed-methodology approach, wherein practical and theoretical stages iterate to develop a computational design system that actively supports craft textile making. As such, this paper acknowledges the intrinsic algorithmic foundation of textiles and proposes the use of shape grammars as a means of systematising and disseminating craft-led methods of thread manipulation. From a conceptual standpoint, it examines the roles of craft knowledge – tacit, or difficult to define – and craft process – dynamic and open-ended – in advancing novel design methodologies. It emphasises the difficulty in capturing and communicating the personal and ever-changing qualities of a craftsperson's experience, and how that leads to practices becoming forgotten and their innovative potential overlooked. By embedding the rules of a craft textile practice within a visual design framework, this project aims to preserve and externalise the tacit knowledge held by craft practitioners, improving its reach across disciplines.

Keywords: craft; computation; textiles; form-finding.

1. Introduction

Recent interest in the development of novel materials, their design and production processes has emerged from a range of different areas of academic inquiry. Within the discipline of textiles, such studies usually originate from STEM disciplines with a workmanship of certainty approach, wherein established methods and tools are applied towards achieving predetermined outcomes (Pye, 1971). Consequently, insufficient attention is given to creative textile processes rooted in hand-based, craft-

DOI number: https://doi.org/10.21606/TI-2023/101.

led techniques, despite their innovation and knowledge generating ability (Albers, 2017). Nevertheless, a turn towards material thinking and craft practices can be observed within academic inquiry (Igoe, 2010; Ingold, 2010; Smith, 2016), bringing forward more freeform approaches to thread arrangements, such as bobbin lace (Irvine & Ruskey, 2014), crochet (Capunaman et al., 2017), or warp-weighted weaving (Harlizius-Klück & McLean, 2021). The goal of such research is the computation of craft textile methods, demonstrating and utilising the algorithmic rules by which they are governed. However, the reliance of textile practice on the presence and use of tacit knowledge puts it in stark contrast to creative disciplines with their more explicit documentation and communication of processes, techniques and findings (Kucukoglu & Colakoglu, 2013; Stiny, 1986).

Here, mathematical analyses of historical textile and pattern arrangements can provide a better understanding of the creative yet methodical processes (Brezine, 2009). The systematisation of textile techniques in line with the principles of workmanship of risk (Pye, 1971) supports craft processes by providing the user with agency over the abundance of possible thread arrangements. It has the potential to expand our current perception of construction possibilities across creative disciplines (Brezine, 2009) which appears especially significant in the digital age with access to more flexible methods of manufacture (Kucukoglu & Colakoglu, 2013). Translation of craft-led making into discrete, computable steps facilitates the explication of the implicit knowledge held by craftspeople, aiding in the analysis and systematisation of ancient or contemporary craft techniques overlooked by industry, expanding our view of social and material cultures (Brezine, 2009; Gürsoy, 2016). Additionally, novel technologies have the potential to enrich existing communities of makers by equipping them with flexible and consistent modes of engaging with computer-aided design tools and processes (Irvine & Ruskey, 2014; Niedderer & Townsend, 2014; Noel, 2020). Concurrently, they have the capacity to advance freeform and made-to-measure construction within the fields of design, architecture, digital fabrication, and robotics (Kolarevic & Klinger, 2008; Muslimin, 2010; Popescu et al., 2021; Veliz Reyes et al., 2019), improving durability of structures and eliminating the need for post-production.

2. Research background

Through its hybrid nature, textiles demonstrate an inherent capacity to blend differing approaches to problem solving, providing a strong foundation for cross-disciplinary inquiry. Textile making encompasses diverse forms of engagement and serves a range of functions – from artistic expression, design and production of practical items to engineering of highly technical fabrics. Textile practitioners possess a diverse set of skills as their occupation simultaneously demands creative, technological, and scientific competence (Albers, 2017). It is the blending of technical and artistic activity that puts textiles at a disciplinary crossroads, while simultaneously being the source of their innovative potential. This paper acknowledges these qualities and utilises hand-based textile practice as a setting for the exploration of concepts from across the fields of craft, construction, and computation.

2.1. Craft textile knowledge

As a domain, craft is usually placed in opposition to other, better-defined fields; it is most often described in relation to art, design, and mechanised or automated manufacture. In the case of textiles, the proximity of these areas is far from arbitrary as craft frequently crosses disciplinary boundaries and finds application in a variety of domains (Dormer, 1997b; Smith, 2016). The predominant distinction from other creative practices is craft textiles' 'reliance on the sensibilities of material understanding' (Niedderer and Townsend, 2014, p.2), which indicates the significance contributed to the textile practitioner's knowledge of materials and the techniques of their manipulation. Whether craft is associated with historical or ethnic hand-making of goods, skilful execution of a preconceived design, or development and production of a one-off piece, a high level of inherent know-how and mastery is assumed (Adamson, 2010; Dormer, 1997a). Their significance to carrying out and advancing one's practice is now widely recognised, although a better understanding and communication of its operational principles are needed to successfully apply it to other areas of creative inquiry.

As this personal know-how of a textile practitioner cannot be fully expressed through conventional textual means, sections of it escape translation (Niedderer & Townsend, 2014). Still, its transmission to other craftspeople, but especially to specialists in other fields, is considered crucial to achieving comprehensive innovation. With the expansion of digital means of engagement with data, new approaches to the storage and sharing of craft textile knowledge should be considered with the aim of its universal application across disciplines. By embedding the tacit understanding of textile techniques in generic design systems, we have the potential to not only improve its distribution, but also establish a craft-based foundation for exploration and generation of new forms, not limited to cloth production (Dormer, 1997a; Harlizius-Klück & McLean, 2021).

2.2. Craft-led textile making as form-finding

In its comparison to the fields of art and design, textile craftwork runs a risk of being considered as merely skilled labour, devoid of creative contemplation. This sentiment is reinforced further by the well-established model of production as merely a practical application of thought (Ingold, 2010), while the focus on craft objects as predominantly functional further neglects the complexity of making (Adamson, 2010). It is thus imperative to acknowledge craft textiles' creativity as derived from the process of formation, rather than its outcomes, as those are never fully predetermined. Furthermore, contemporary craftwork is often carried out entirely on hand-looms, wherein highly complicated and structural forms are achieved through hacking of tools and hands-on manipulation of threads (Albers, 2017). Such levels of physical interaction in the weaving process would be challenging in industrial environments due to the elaborated machinery set-ups, high speed of operation, and the general objective of increasing automation, thus reducing human input.

Similarly, the increasing availability of rapid, automated fabrication has redefined designers' relationship to materials, reinstating making as part of a design practice (Gürsoy, 2016; Muslimin, 2010; Noel, 2020; Veliz Reyes et al., 2019). Incorporation of hands-on engagement in a modern, highly technological setting has caused many to reconsider the value of sensory learning. In her thesis, Gürsoy (2016) differentiates between making of and making for – the first depicts making as realisation of a preconceived design, while the latter serves an active role in the process of 'ideation, representation and materialization' (Gürsoy, 2016, p.18). Here, the acts of cognition and making interlink and alternate, shifting 'from visual to spatial reasoning' (Gürsoy, 2016, p.40). This cycle of observation and transformation was built on the well-established design theory of seeing-moving-seeing proposed by Schön and Wiggins (1992) and links to the concept of reflection-in-action which delineates the analytical thought processes present in all stages of a creative task. This, in turn, suggests that both the theoretical and the practical phases involve implementation and generation of knowledge, whether deliberate or intuitive, intellectual, or tacit. The bridging of seemingly disparate actions and approaches is especially evident in the case of textiles, wherein different forms of engagement come together in a seamless process of creation.

2.3. Computation of craft textiles

Although the word 'computation' is often used to depict the narrow sphere of digital processing, some ancient textile techniques were used as tools for calculation, record keeping, and systematic communication. Weaving drafts and later punch cards served as a basis for the first computers, confirming the presence of mathematical principles governing textile making (Brezine, 2009; Harlizius-Klück & McLean, 2021). Recently, it has been suggested that only a narrow range of computational frameworks can be expressed through digital means and a more general approach, encompassing everyday activities of processing and organising information, has been proposed (Knight & Stiny, 2001). In 'analogue' practice, computation can be recognised as general reasoning, a deductive approach to a problem, accounting for the algorithmic thinking and movements which occur during hands-on engagement with one's work (Capunaman et al., 2017; Gürsoy, 2016). Craft textile processes could therefore be defined as computational, as they follow a course of actions set by the rules of its materials and centuries of cultural learning. This does not negate the instinctive and responsive qualities of craft; in fact, computing can be a flexible, open-ended form of problem-solving, rather than a solution-oriented one (Yazici, 2020).

Considering the close link between textiles and technology, the distinct rules of thread manipulation have proven particularly receptive to formalisation as a universal construction method (Dormer, 1997b), lending themselves to numerous architectural applications (Capunaman et al., 2017; Muslimin, 2010; Popescu et al., 2021). In the case of weaving, its mathematical rules are now well understood partly due to their intrinsically binary nature and as a result of extensive documentation efforts. However, proving difficult to automate, textile assemblies exploiting hand-manipulation of threads have been excluded from most research, despite their inventive capacity explored by craft and art practitioners such as Peter Collingwood and Lenore Tawney (Brezine, 2009; Smith, 2016). The continued progress in freeform computer-aided construction adds further significance to the aim of improving our understanding and cross-disciplinary dissemination of craft techniques of material manipulation (Kolarevic & Klinger, 2008; Veliz Reyes et al., 2019).

2.4. Craft-led textile notation

Weaving, as arguably the most industrialised method of fabric manufacture, requires a consistent system of representation, allowing for ease of communication and repeatability (Brezine, 2009). While traditional weave diagrams represent the rules of textile manufacturing algorithmically, they do not resemble the real-life practice of hand-weaving. In comparison to the complex, often multi-faceted processes of crafting, notation through weaving drafts is simplistic and can distort the performative quality of textile making. It is aimed at mechanised production and, as such, better suited for presentation of results, rather than exploration of potential designs.

Likewise, in a computational context, presently available CAD systems are ill-suited to the exploratory stages of any creative activity, as they require input of predetermined parameters (Harlizius-Klück & McLean, 2021; Jowers et al., 2008; Kucukoglu & Colakoglu, 2013; McKay et al., 2008; Yazici, 2020). Craft textile processes rely on intuitive, flexible recognition and manipulation of emergent forms, which is not supported by most CAD tools. Thus, more responsive, visual means of computation of craft textiles should be considered to facilitate their adaptation into a generic textile design framework. One method of visual computation which fulfils those requirements is shape grammars, a language-like, rule-based approach to designing with shapes (Knight & Stiny, 2001; Stiny, 1986). Although rooted in mathematics, grammars use visual rather than numerical notation, and allow for ad-hoc manipulations of individual components which do not have to be predetermined. The user remains in control of recognising, selecting, and manipulating the emerging forms which supports the craft textile processes of idea and form generation. As such, this paper proposes the use of shape grammars as a means of analysis, codification, and communication of craft-based techniques of thread manipulation with the aim of establishing a functional cross-disciplinary approach to textile-led form-finding.

3. Research approach

The methodological framework of this project borrows from the principles of research-through-design and action research. Research-through-design acknowledges the value of making in exploration and empirical testing of ideas and, as such, is considered most fitting to creative research and has frequently been used in design-led academic inquiries (Niedderer & Townsend, 2014; Veliz Reyes et al., 2019). On the other hand, action research supports the continual emergence of new findings and interpretations, which the dynamic nature of craft necessitates. Here, the practical and analytical stages iterate, continually refining the grammar design (Figure 1).

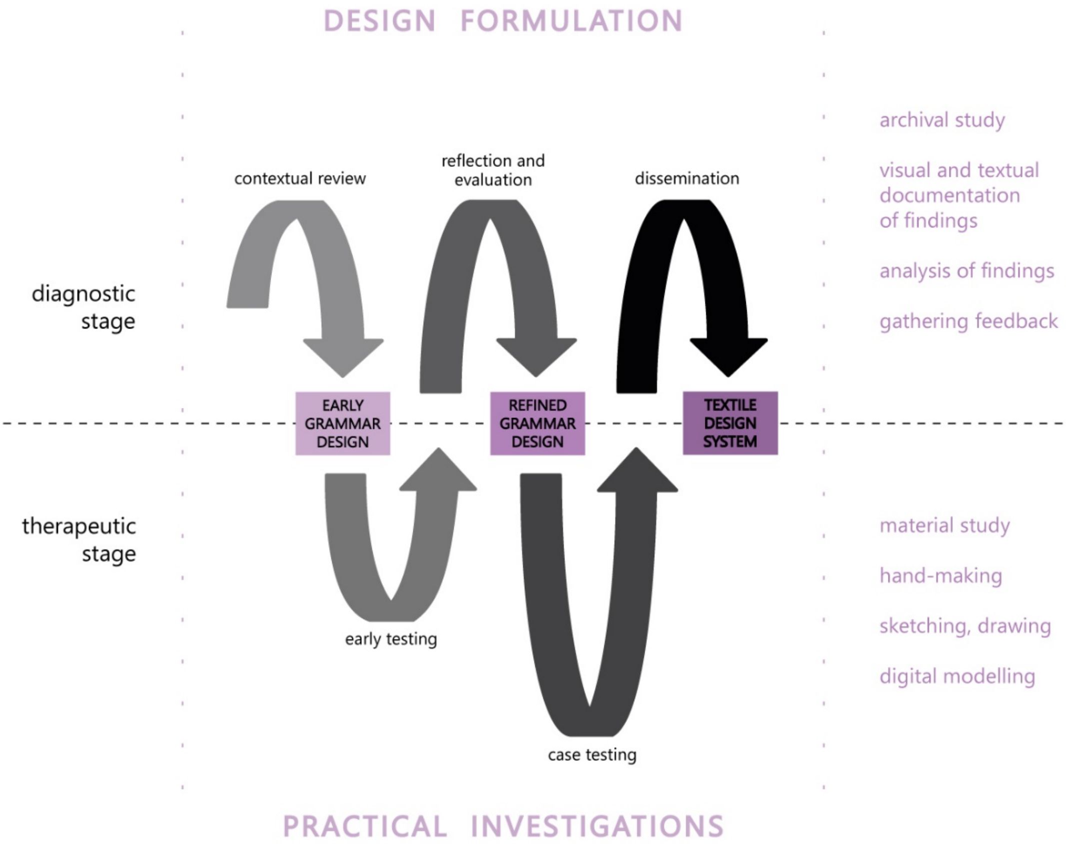

Figure 1 – Methodological framework of this research

The aim of this paper is to present and discuss the process of developing a craft-led textile design framework by systematising existing 'hacking' methods of thread manipulation using shape grammars as a means of visual computation. Situated at the intersection of the disciplines of craft, textiles, and computation, this research benefits from a mixture of theoretical and practical approaches to problem solving and knowledge generation. Form-finding is approached through hand and computer-based methods, such as textile making, drawing, and programming, and rooted in the craft textile knowledge of the first author. Warp manipulation is selected as a specifically hand-based textile technique not accounted for in existing notational systems. While the primary goal is not the invention of a textile technique, the authors acknowledge that the outcome of this research has the potential to facilitate novel out-of-plane construction.

3.1. Hacking weave

As a method of engagement with craft textile practice (Irvine & Ruskey, 2014), the hacking of tools and processes has often been used in response to new technologies which, while saving time and labour for industry, would instead 'lessen the freedom of the weaver' (Albers, 2017, p.7) . Indeed, hobby craft booklets, magazine articles and, more recently, online blogs, comprise a wealth of 'how-to' guides for makers wanting to experiment with hand-based techniques and equipment. Here, terminology such as 'byways', 'off-the-loom' or 'fingers-as-tools' are frequently used to denote the divergence and novelty within domestic craft practices.

One of the limitations of current weaving technologies is the inability to alter the positioning of the warp threads outside of the weaving plane. These are usually attached to beams at the back and front of a loom, passed through individual heddles arranged on shafts in a specific order, and then through a reed, which spaces them out evenly. This arrangement secures the threads, ensuring even tension and distribution of the warp, maintaining a uniform weaving surface. However, this also fixes a section of the filaments to one geometrical plane, restricting their movement (Brezine, 2009). While techniques such as leno or its Japanese version, Karamiori (Marshall, 2009), offer some flexibility in warp manipulation, their out-of-plane construction capacity is still limited by permanent attachment of warp threads. This project addresses this limitation by securing individual warp threads temporarily, enabling them to be maneuvered independently at different stages of production. Here, the warp-weighted loom serves as inspiration, as the use of loom weights instead of a front beam allows for out-of-plane movements of the warp (Harlizius-Klück & McLean, 2021).

3.2. Shape grammars as a method of visual computation

Commonly described as a pictorial algebra, the format of shape grammars is analogous to that of mathematical calculations, carried out with shapes rather than numbers or symbols (Knight & Stiny, 2001). The process begins with defining the initial shape **A** on the left side of the computation, the computing rule → denoting 'replace with', and the resulting shape **B** on the right side of the computation:

A → B

This rule configuration forms the core of any grammar and remains unchanged regardless of its application, whereas the shape elements can be adjusted and new rules added by the user. These can be based on existing designs – used to create new forms in the style of the original – or be entirely independent of any aesthetic or structural conventions. This adaptability is what deems shape grammars suitable for both the exploratory and formal stages of creative activities, finding application in the systematisation of other craft-led construction techniques, including Celtic knots (Jowers & Earl, 2011), bamboo weaving (Muslimin, 2010), or wire bending (Noel, 2020). While the first example focused on developing a theoretical design framework for knotwork, both the weaving and the wire bending grammars have been used to formulate and construct large-scale architectures based on the craft techniques they codified. This study adopts an analogous approach to the computation of craft-led methods of warp manipulation with the aim of producing a textile design framework suitable for cross-disciplinary applications of both hand-based or automated, small- or large-scale fabrication.

4. Research practice

The practical investigations undertaken as part of this study included two phases of textile making – firstly as an approach to form-finding and then as a method of testing the visual notation framework. Computational designing was implemented between the two phases of crafting, constituting the translation from an analogue to a digital format of constructing.

4.1. Textile-led form-finding

In line with the research methodology of craft-led weave hacking, a twining-like mechanism of warp manipulation was established (Figure 2), forming the basis of the material experiments within this project. The practical investigations in this research used a simple board loom, followed a top-down weaving setting and a left-to-right order of emergence (Figure 3a). They were guided by the desire to study and understand the spatial relationships of individual components in specific thread arrangements; however, they were not predetermined. Instead, the warp switching mechanism was explored intuitively, based on the haptic feedback from the materials and the researcher's own experiential knowledge of weaving.

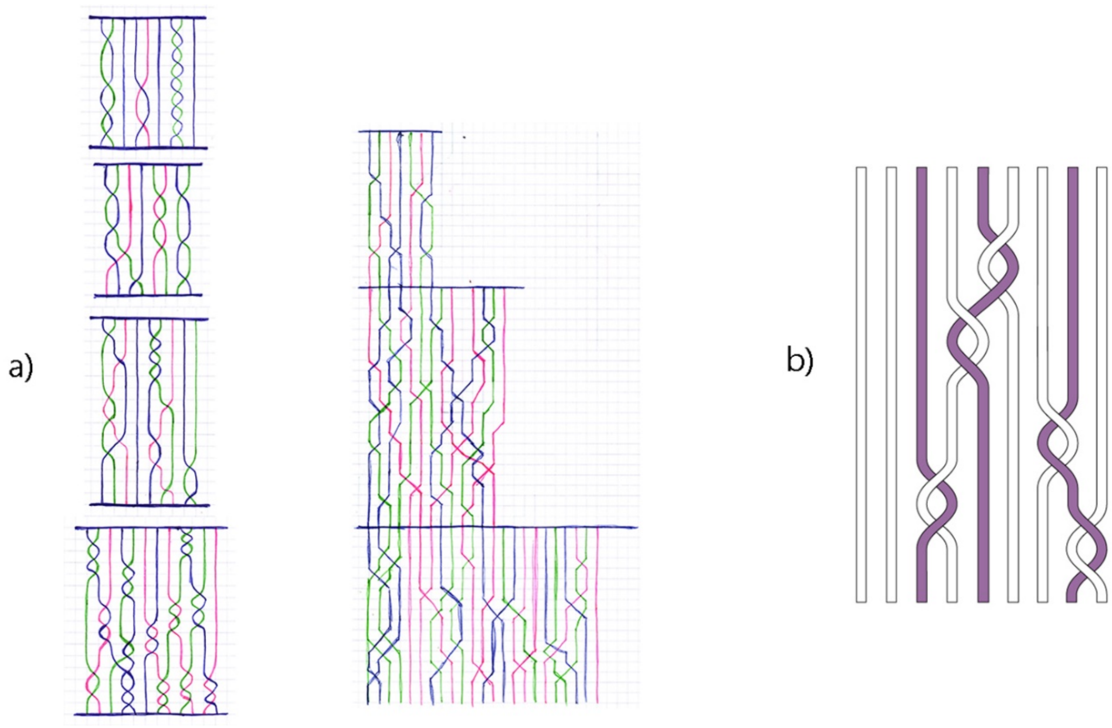

Figure 2 - Hacking of warp with a twining-like mechanism: a – experimental hand drawings; b – digital representation

Throughout the process of crafting the freeform thread arrangements, design ideation was intertwined with movement execution, unfolding in response to earlier transformations and simultaneous reflection on emergent forms. The later visual notation of the material sample (Figure 3b) followed the mechanisms observed through this practice, ensuring consistency with the real-life process of textile crafting.

a) b)

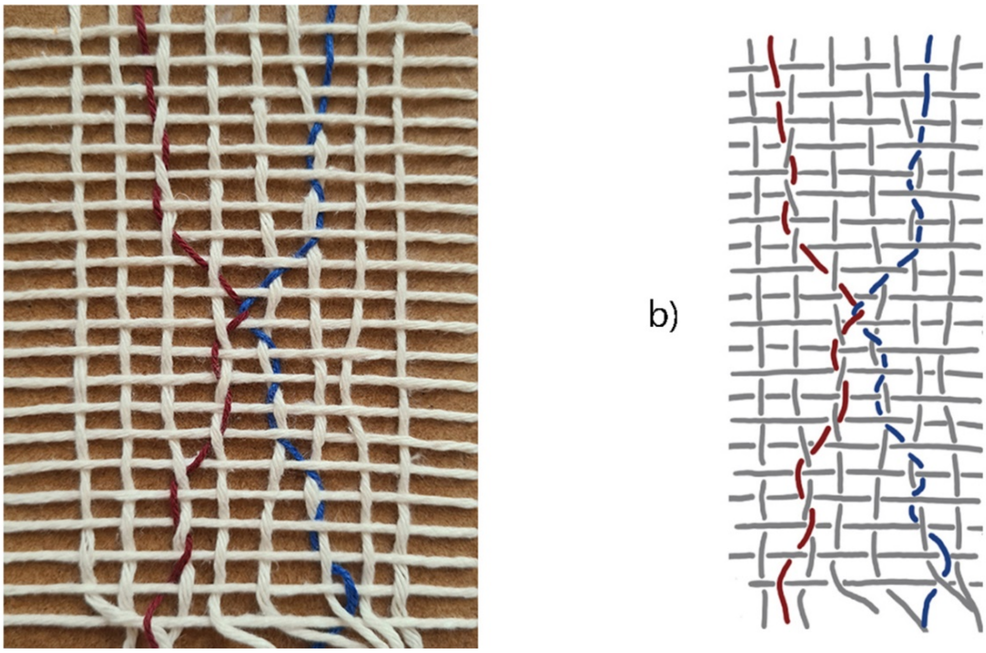

Figure 3 – Weave structure including leno-like and weftless warp switching: a – hand-woven sample; b – material-led drawing

4.2. Establishing the weaving grammar

Prior to exploring the warp switching technique computationally, a set of basic weaving transformations was established based on a hand-drawn notation of a plain weave structure (Figure 4a). The resulting grammar rules T1 and T2 describe the spatial relationship between individual warp (vertical) and weft (horizontal) threads, while rules T3-T6 portray the arrangements possible between a singular warp and 2 neighbouring weft threads (Figure 4b). Rules P1 and P2 denote the symbolic extension of the warp thread – such a modular representation of the continuous components in weave facilitates ad-hoc changes throughout the computing process.

To test the suitability of the proposed grammar format to the systematisation of hand-based textile making, multiple existing weave structures were produced using the above rules. The successful computation of a plain weave (Figure 5a) and 1/3 twill (Figure 5b) structures confirmed the grammar's capacity for generating existing weave patterns. To extend its applicability to new designs that follow the same stylistic convention, new rule formats were first explored by hand, based on existing weave structures (Figure 6a), and then notated digitally (Figure 6b) to ensure uniformity of presentation. This led to the expansion of the basic weaving grammar to include the proposed mechanisms of warp thread manipulation where rules P3-P6 represent the action of warp switching, while rules T7-T10 describe the spatial arrangement of wefts before and after the switch. The resulting grammar format was then used to analyse and codify the hand-woven structures and as a design tool for computational form-finding.

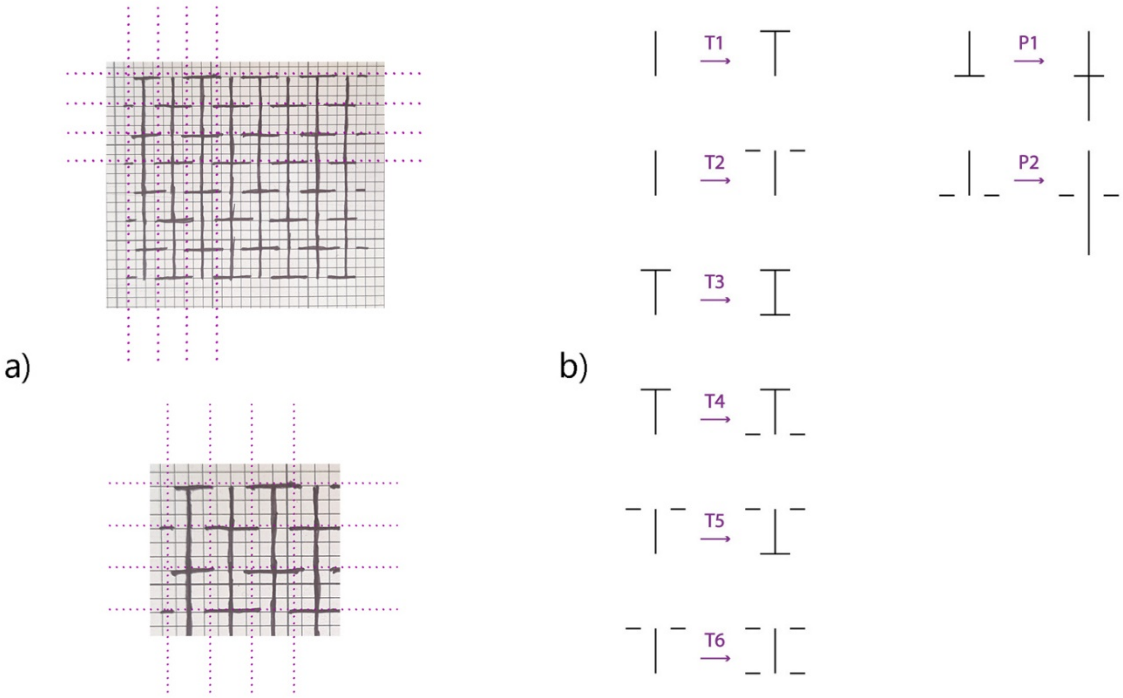

Figure 4 – Development of a basic weaving grammar: a - extraction of rules from drawings; b – wef(T) and war(P) rules

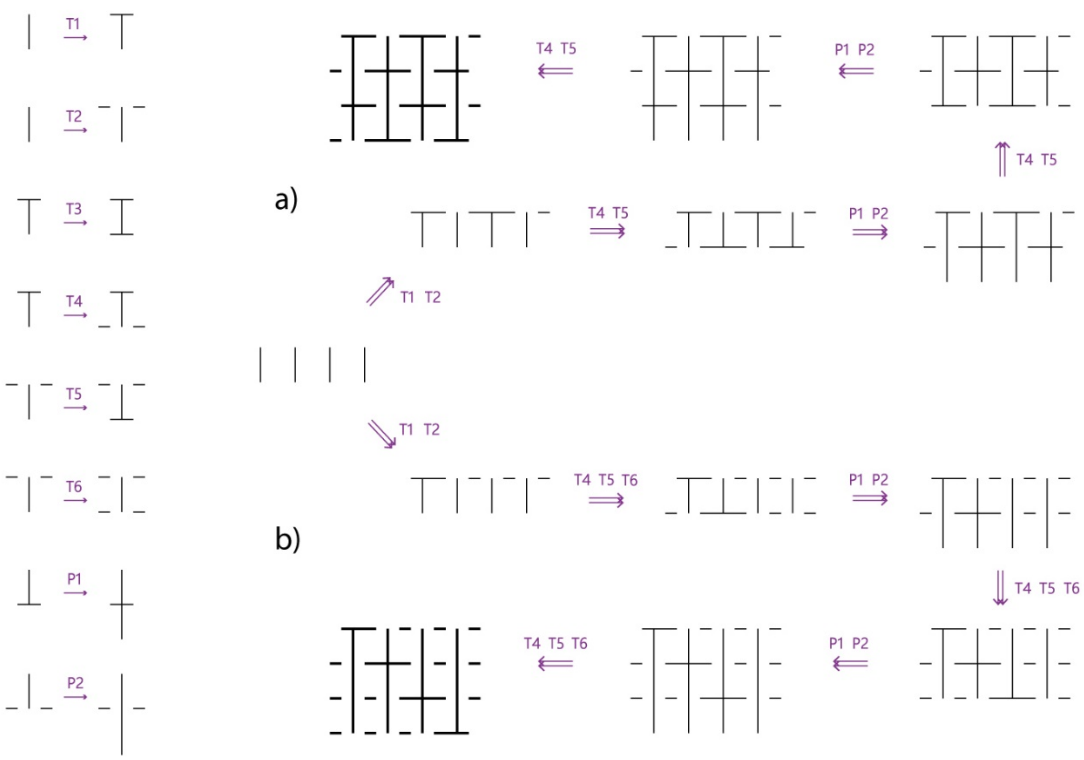

Figure 5 – Grammar-based computation of existing weave structures: a – plain weave; b – 1/3 twill

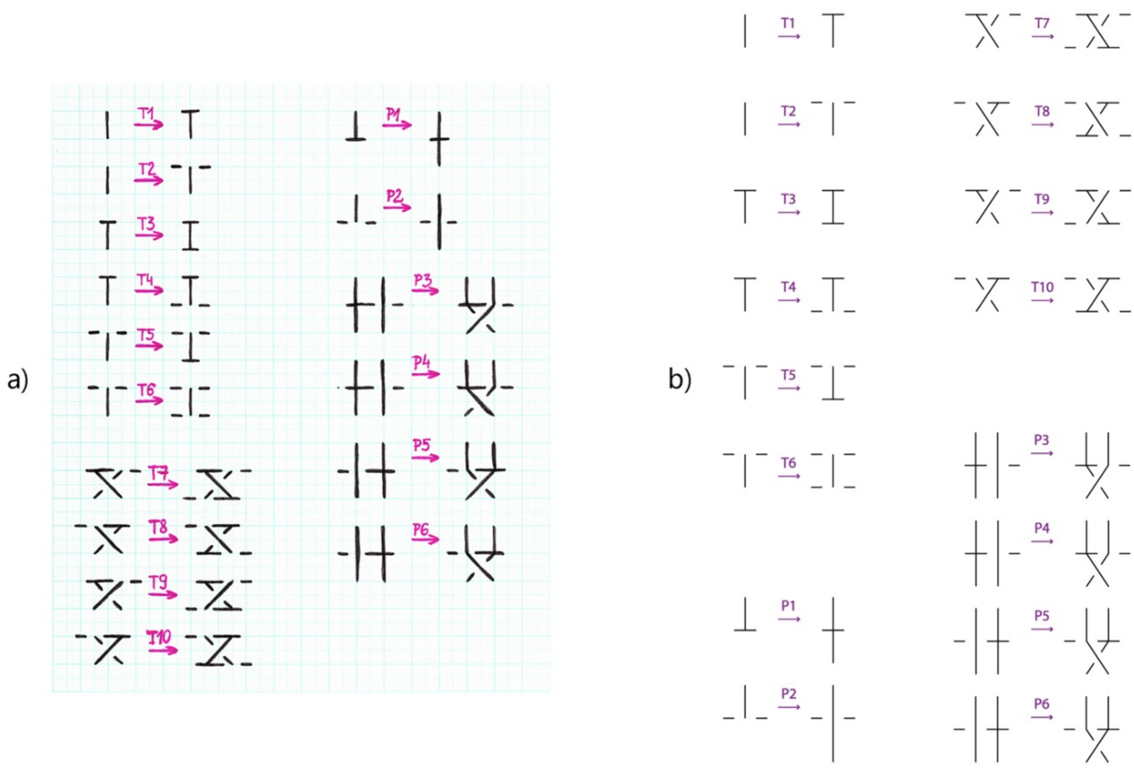

Figure 6 – Grammar rules for weaving including warp switching: a – hand drawings; b – digital notation

4.3. Computational form-finding

In the next step, the material sample developed at the beginning of the study was notated according to the established grammar format (Figure 7). From this, an individual weftless twist rule was extracted and expanded to include all possible arrangements of neighbouring warps and wefts. This process of computational form generation resulted in 16 separate configurations which were then compared visually and eliminated according to the requirements of the project. Here, six arrangements were found to be repeating and thus discarded, while the remaining ten were analysed further in the last phase of practical investigations (Figure 8).

Implementing the modular structures within a weaving set up clarified the spatial relationships between individual groups of threads in a larger textile architecture. It served as a means for a functional examination of the computationally generated forms, ensuring the validity of the proposed grammar framework. Through this stage of making, one arrangement was found to result in a different type of structure and seven did not fulfil the requirement to maintain the interlocking of warp threads. Consequently, two manipulations were systematised and codified as new grammar rules. It should be noted that these structures have never been described in the context of weaving and, as such, add to the structural vocabulary of a contemporary textile designer.

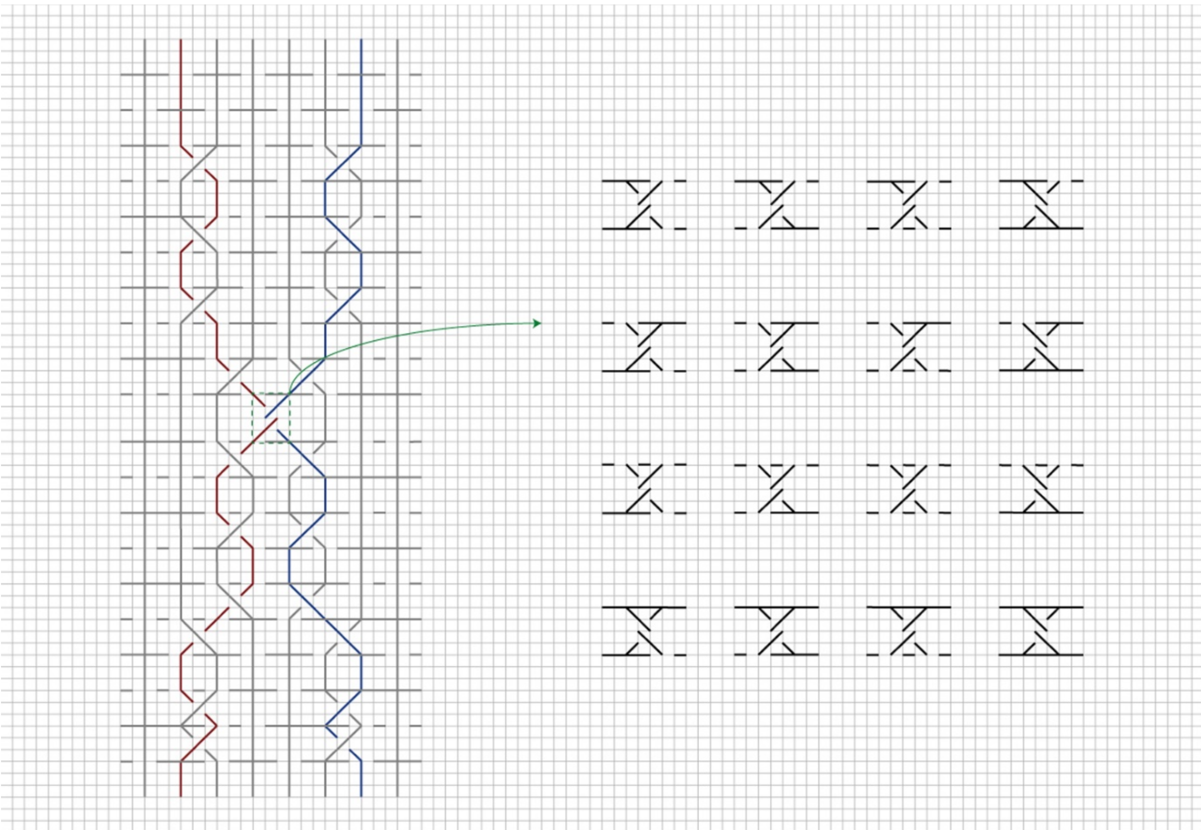

Figure 7 – Grammar-based notation of the material sample and all possible weftless rule computations

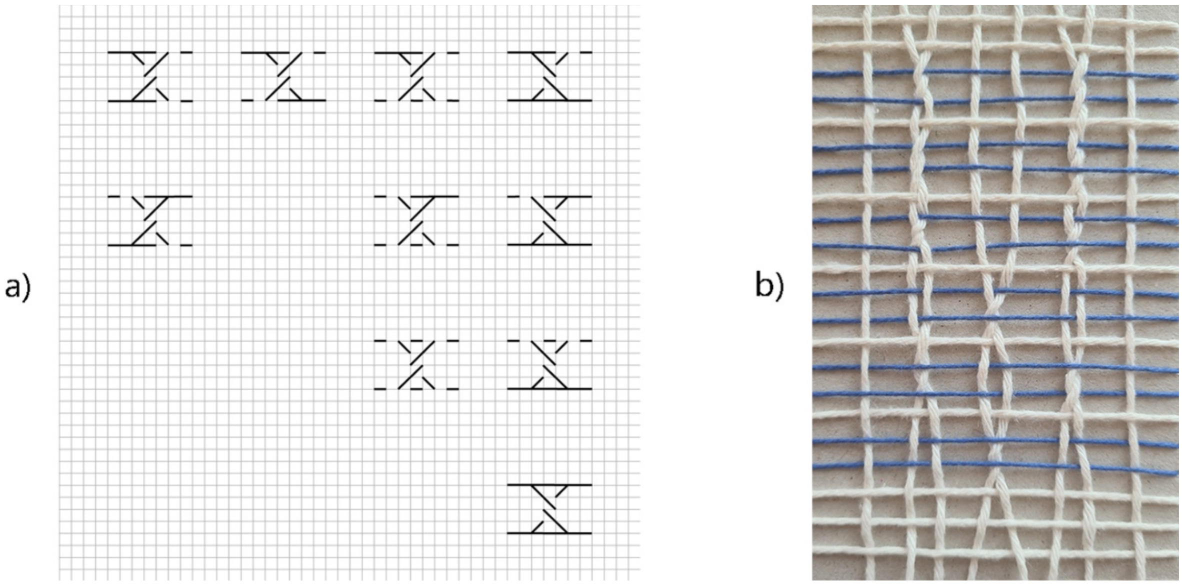

Figure 8 – Testing of the weftless grammar rule (a) computations through hand-weaving (b)

Furthermore, grounding the grammar format in real-life mechanisms of craft textile making afforded a process- rather than outcome-led digital visualisation of weave. By presenting the textile sample as a collection of modular shapes, the computational notation explicates the individual actions of the maker throughout the weaving process. This facilitates the systematisation of the craft textile practice as repeatable – or computable – steps, enabling its dissemination within and outside of the discipline of textiles.

5. Reflection

A textile-led approach to form-finding as part of a cross-disciplinary research is presented in Section 4, wherein we describe and discuss the process of idea and form generation through a mix of craft-based and computational methods. Further, the research illustrates the practical progression from experimental making to analogue and digital notation, and the computation of textile structures.

Although experimental, the process of hand-based form-finding in the first phase of investigations was deeply rooted in the existing craft knowledge of the researcher. The weaving process was further informed by the sensory feedback from materials and the continual reflection on the weaver's movements. The craft-led approach to textiles was maintained throughout the later stage of translating the physical material to a visual notation, ensuring continuity of presentation across the different formats. As a result of the weave hacking, new knowledge of thread manipulation in weaving was gained and a new structure of warp thread switching identified.

The computational phase began with a digital notation of the hand-based drawings of structures. New arrangements were generated based on the previously defined grammar and then tested through hand-weaving. It should be noted that the computations could have been carried out entirely by hand and the choice to notate and apply them digitally was made by the researcher with the aim of improving workflow and uniformity of representation. The new structures were evaluated and amended during both the computing and making steps, aiding the continual refinement of the grammar. Next steps in developing the design framework will aim to validate the proposed weave grammar through peer testing, as well as case studies examining a range of material, structural, and spatial parameters.

Both hand-making and digital-making provided exploratory opportunities, indicating a strong link between craft thinking and computational thinking. As such, the findings from this research stretch beyond the development of a computational tool for craft-led textile design and confirm the validity of textile practice as a means of conducting cross-disciplinary research.

6. Conclusion

The research presented in this paper demonstrates textiles' capacity to bridge gaps between the disciplines of craft and computation, and to serve as a foundation for the exploration and development of mixed methodologies. By applying craft-led approaches to textile making as a means of form-finding, it utilises the rule-based, yet creative nature of craft practices and the associated knowledge. In employing shape grammars as a method of visual computation, it facilitates the analysis, systematisation, and dissemination of craft textile techniques without distorting their dynamic qualities. As such, the impact of this research stretches across the disciplines of textiles, craft, and computation while, simultaneously, creating opportunities for further research across the areas of archival study, architectural design, and material sciences.

Considered as not only a production technique but rather an approach to active synthesis of forms, craft has the capacity to contribute to the development of novel methods of design and manufacture. Conversely, it is important to consider the ways in which computational design frameworks could provide support to craft communities, particularly by improving the communicability and accessibility of technical, yet often implicit, knowledge. They could aid in the analysis and systematisation of ancient or contemporary craft techniques overlooked by industry, expanding our view of social and material cultures. Correspondingly, an in-depth understanding of how weavers identify and transform emergent textile forms could enable creation of generative design systems, allowing for a less restricted investigation and synthesis of complex, freeform architectures.

Finally, if developed in line with the mechanics of a craft process, digital modelling and production tools could equip the maker with new, interactive means of engagement with computation and pattern generation. The recognition of rules present in craft textiles and their notation through computational means could facilitate the switch to the hybrid, cross-disciplinary practices made possible by the digital era.

References

Adamson, G. (2010). *The Craft Reader*. Bloomsbury.

Albers, A. (2017). *On Weaving* (N. F. Weber, M. Cirauqui, & T. a. Smith, Eds.). Princeton, New Jersey: Princeton University Press.

Brezine, C. (2009). Algorithms and automation: the production of mathematics and textiles. In E. Robson & J. Stedall (Eds.), *The Oxford handbook of the history of mathematics*. Oxford University Press.

Capunaman, O., Bingöl, C. K., & Gursoy, B. (2017). Computing Stitches and Crocheting Geometry. CAAD Futures, Istanbul Technical University, Istanbul.

Dormer, P. (1997a). Craft and the Turing Test for practical thinking. In P. Dormer (Ed.), *The Culture of Craft*. Manchester University Press.

Dormer, P. (1997b). Textiles and technology. In P. Dormer (Ed.), *The Culture of Craft*. Manchester University Press.

Gürsoy, B. (2016). *Formalizing Making in Design* Istanbul Technical University]. Istanbul.

Harlizius-Klück, E., & McLean, A. (2021). The PENELOPE Project: A Case Study in Computational Thinking. In L. Schulze Heuling & C. Filk (Eds.), *Algorithmic and Aesthetic Literacy. Emerging Transdisciplinary Explorations for the Digital Age.* Verlag Barbara Budrich. https://doi.org/10.5281/zenodo.4680852

Igoe, E. (2010). The tacit-turn: textile design in design research. *Duck Journal for Research in Textiles and Textile Design*, *1*, 1-11.

Ingold, T. (2010). The textility of making. *Cambridge Journal of Economics*, *34*(1), 91-102.

Irvine, V., & Ruskey, F. (2014). Developing a mathematical model for bobbin lace. *Journal of Mathematics and the Arts*, *8*(3-4), 95-110. https://doi.org/10.1080/17513472.2014.982938

Jowers, I., & Earl, C. (2011). Implementation of curved shape grammars. *Environment and Planning B: Planning and Design*, *38*(4), 616-635. https://doi.org/10.1068/b36162

Jowers, I., Prats, M., Lim, S., McKay, A., Garner, S., & Chase, S. C. (2008). Supporting Reinterpretation in Computer-Aided Conceptual Design. *EUROGRAPHICS Workshop on Sketch-Based Interfaces and Modeling*.

Knight, T., & Stiny, G. (2001). Classical and non-classical computation. *Architectural Research Quarterly*, *5*(4), 355-372. https://doi.org/10.1017/s1359135502001410

Kolarevic, B., & Klinger, K. R. (2008). *Manufacturing material effects : rethinking design and making in architecture / edited by Branko Kolarevic & Kevin R. Klinger*. New York ; London : Routledge, c2008.

Kucukoglu, J. G., & Colakoglu, B. (2013). Algorithmic Form Generation for Crochet Technique: A study for decoding crocheted surface behaviour to explore variations. eCAADe 31, University of Technology, Delft.

Marshall, J. (2009). *Traditional Dyeing and Weaving: Karamiori*. http://www.johnmarshall.to/H-TradTech-Karami.htm

McKay, A., Jowers, I., Chau, H. H., De Pennington, A., & Hogg, D. C. (2008). Computer Aided Design: An Early Shape Synthesis System. CADAM, Sanya, China.

Muslimin, R. (2010). Learning from Weaving for Digital Fabrication in Architecture. *Leonardo*, *43*(4), 340-349. https://doi.org/10.1162/leon_a_00007
Niedderer, K., & Townsend, K. (2014). Designing Craft Research: Joining Emotion and Knowledge. *The Design Journal*, *17*(4), 624-647. https://doi.org/10.2752/175630614x14056185480221
Noel, V. (2020). Situated Computations: Bridging Craft and Computation in the Trinidad and Tobago Carnival. *Dearq*(27).
Popescu, M., Rippmann, M., Liew, A., Reiter, L., Flatt, R. J., Van Mele, T., & Block, P. (2021). Structural design, digital fabrication and construction of the cable-net and knitted formwork of the KnitCandela concrete shell. *Structures*, *31*, 1287-1299. https://doi.org/10.1016/j.istruc.2020.02.013
Pye, D. (1971). *The nature and art of workmanship* (Revised edition. ed.). Studio Vista.
Schön, D., & Wiggins, G. (1992). Kinds of seeing and their functions in designing. *Design Studies*, *13*(2), 135-156. https://doi.org/10.1016/0142-694x(92)90268-f
Smith, T. (2016). The Problem with Craft. *Art Journal*, *75*(1), 80-84. https://doi.org/10.1080/00043249.2016.1171544
Stiny, G. (1986). Computational foundations of architectural design. *Environment & Planning B: Planning and Design*, *13*, 127-132.
Veliz Reyes, A., Jabi, W., Gomaa, M., Chatzivasileiadi, A., Ahmad, L., & Wardhana, N. M. (2019). Negotiated matter: a robotic exploration of craft-driven innovation. *Architectural Science Review*, *62*(5), 398-408. https://doi.org/10.1080/00038628.2019.1651688
Yazici, S. (2020). Rule-based rationalization of form: learning by computational making. *International Journal of Technology and Design Education*, *30*(3), 613-633. https://doi.org/10.1007/s10798-019-09509-5

About the Authors:

Sylwia Orynek: is a PhD Candidate investigating three-dimensional textile construction through a combination of art, design, and engineering approaches. Her academic practice incorporates archival study, making, and computing to explore the value of heritage techniques and experiential knowledge in novel design frameworks.

Briony Thomas: is Associate Professor of Design Science, jointly appointed across the Faculties of Arts and Engineering & Physical Sciences, and Chair of Leeds Cultural Education Partnership. Her work brings together collaborations across science and culture through participatory action research and creative engagement.

Alison McKay: is Professor of Design Systems in the School of Mechanical Engineering. Her research focuses on different kinds of design systems and aims to facilitate improved modes of working through the exploitation of digital technology and the establishment of novel design methods and tools.