W(hole): An alternative approach to weave structure visualisation

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Abstract

This thesis is an exploration into the notation of weave structures. To do so, it analyses weave geometries from the perspective of negative space — here referring to the empty area in-between vertical warp threads and horizontal weft threads. Central to the research are the questions: what is the potential role and value of negative space in weave structure visualisation and can a holistic approach to the visualisation of weave structure uncover a new understanding of cloth construction and properties?

Sparse attention has been given to weave structure notation prior to the First Industrial Revolution. This suggests that early weaving knowledge was likely to be tacitly passed on and learnt through the experience of making. Today, the modern notational system — a grid-like matrix of coloured squares — only indicates the movement of yarns on the machine (chapter 03). While weavers understand very well this way of visualising weave structure, others outside of the discipline struggle to make sense of it or understand woven cloth's fluid nature — hindering innovative engagement with the craft and limiting its construction methodology to what the machine can/not do. The thesis investigates the potential development of an alternative weave structure visualisation for others to understand the tacit and experiential knowledge that cloth creation necessitates; and for weavers to approach their craft in holistic ways. This could help step away from understanding weave structure notation as a sole manufacturing tool.

Following a practice-led methodology based on a 'make-think' approach to research, the study focuses on visualising the 'unseen' by asking: what is it that is not being looked at? (chapter 02). In order to understand empty space as a 'material' space (chapter 04), research draws on concepts within textile theory, semantics, fractal geometry and architecture for the purpose of using negative space as a practical tool to investigate weave geometries. Weave structure visualisation is explored through making processes while also including digital methods often used in material engineering (chapter 05 and 06). Initially, two experimental case studies present qualitative exploration both in the physical and virtual realm. First studied as a 'structure unit' and then within a 'repeat', findings identify that negative spaces repeat themselves in irregular

ways — challenging the core parameter of repetition. The idea that rigid construction principles that produce fluid woven textiles places weaving as an antithetical craft — a notion that inspired its binary model is then put into question. This was explored through grey nuances (chapter 06), which reveals empty and occupied space's interdependence. The study finds that although grey shades hinders the readability of weave structures, the proposed visualisation highlights the importance of craft weaving methods in order to develop a more holistic understanding of the technique. By questioning the fundamental knowledge contained within woven cloth construction, this alternative approach enables the craft to open up to interdisciplinary research (chapter 08). This is pertinent in regards to the development of novel assembly systems, which increasingly demand non-linear and organic modes of thinking. As a result, the research has value for weaving and other disciplines that aim to find alternative ways of doing things.

"This thesis represents partial submission for the degree of Doctor of Philosophy at the Royal College of Art. I confirm that the work presented here is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis. During the period of registered study in which this thesis was prepared the author has not been registered for any other academic award or qualification.The material included in this thesis has not been submitted wholly or in part for any academic award or qualification other than that for which it is now submitted."

Ariane Camille Fourquier

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Glossary

Binary: base 2 system of construction / notation

Biocomputation: using living organisms to undertake computation processing

Biodesign: utilising organisms's properties to solve design problems and create new materials, within and outisde of the textile research realm

Bobbin lace: lace fabric done with yarns wound on bobbins

Braiding: plaiting of multiple yarns together to form a structured fabric

Cellulose-based fibres: vegetal organic fibres, including cotton, linen, hemp, among others

Cloth (also known as **textile** or **fabric**): material structured construct made of fibres and yarns

Computational biology: the creation of frameworks that follow cellular processes

Dent: gaps within the reed

Doup: soft loop-like device attached onto a shaft and passed through a heddle

End: one single vertical yarn part of the warp

Fabric (also known as **textile** or **cloth**): material structured construct made of fibres and yarns

Heddle: metal or cord stem with a hole through which each horizontal yarn is threaded, attached to a shaft

Hygroscopic motion: swelling and shrinking of natural cellulosic fibres under moisture exposure

Jacquard loom: loom whose mechanism enables the lifting of each warp yarns individually

Jacquard head: cylindrical apparatus designed to be attached to a treadle loom and able to read punched cards

Knitted lace: technique of knitting defined by holes within the textile's structure

Knitting: interlocked fibrous structure made with one single yarn that forms rows of loops

Knotting: Tying of knots in a yarn to make a fibrous net-like structure

Leno / gauze: weaving technique involving sets of two warp yarns that twist around each other

Lifting plan: notation of the lifts of each shaft on a loom

Nano-scale: one billionth scale

Macarmé: textile technique made by knotting strands of yarns in a geometric design

Macro-scale: large scale

Mass-production: large scale production

Micro-scale: one millionth scale

Orientation control variable: controled or unchanged position of yarns

Pick: one vertical yarn with a warp

Reed: a comb-like device used to beat horizontal yarns

Repeat: the reiteration of a structure unit

Reproducibility: ability to be copied

Reproduction: repetition of a copied thing

Scalability: ability to change in scale/amount

Shaft: frames on a loom that hold the heddles

SMA: Shape Memory Alloy

Sprang: interlacing of sets of yarns to create a stretchy textile structure and characterised by hole creation

Structure unit: one single negative space / base unit

Synthetic biology: redesigning of orgamism's behaviour for their implementation within a textile construct

Textile (also known as **cloth** or **fabric**): material structured construct made of fibres and yarns

Threading plan: notation of the order in which threads are threaded on a loom

Treadle loom: floor loom operated by the movement of the weaver's feet on pedals

Warp: set of vertical yarns mounted and threaded on a loom

Weave structure: perpendicular structure in which horizontal yarns pass under/over vertical yarns

Weave structure notation (also known as **weave plan**): grid notation which colored squares indicate the lift of each warp end on each weft pick

Weaving: perpendicular interlacement of horizontal and vertical yarns to form a material structure

Weave plan (also known as **weave structure notation**)**:** grid notation which colored squares indicate the lift of each warp end on each weft pick

Weft: set of horizontal yarns to weave with on a loom

Notes on reading the thesis

In this research, the discussion is peppered throughout the thesis, and located at the end of each case studies. This is because analysis of the findings paired with conceptual reflection enabled the practical experimentation to proceed. For the sake of clarity, I have outlined these sections with a speckled black/white/grey vertical marker-line situated on the right hand side of the concerned pages (pp. 88-94; pp. 97-100; pp. 109-115)

Discussion marker: 

Practice is partially integrated within the thesis, throughout case studies (i), (ii) and (iii), respectively in chapter 05 and 06. The full body of practice is grouped in a separate file titled 'accompanying material'. It is advised to explore this body of work at the end of chapter 05 and throughout chapter 06. This portfolio consists of rough notes, technical drawings made pre- and during weaving the leno samples, these helped design and make sense of how leno weave structure operates on the machine. It also includes drawings of the 'repeat' (case study (ii), chapter 05) and drawings and tracings in grey nuances (case study (iii), chapter 06). As part of the accompanying material is a video showcasing the animated X-Ray CT scanned samples. The reader is advised to watch the video at the end of chapter 05.

Diagrams that help make sense of the findings of the four case studies are inserted at the end of chapter 07 (p. 127). To ensure the readability of the diagrams, the page direction changes: portrait to landscape. This also applies to the diagram on p. 24 outlining the chronological development of this thesis.

For my late grandmothers, Nani and Marcelle, with whom I share a love for textiles

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01.

Introduction

In *The Count of Monte Cristo* (Dumas, 1846), priest Faria tells Edmond Dantès how he managed to decipher the missing part of a testimony that would lead to the most incredible treasure. He says:

> Me, who, thanks to the remaining fragment, guessed the rest by measuring the length of lines by the ones of the paper and by piercing through the hidden sense by means of the visible sense, as one guides oneself in a subterranean path by a remnant of light which comes from above.
> (p. 201)

This excerpt suggests that the "hidden", both metaphorically and practically, is at times what might lead to the uncovering of the full meaning of things. Today, I could write that this practice-led research into weave structure notation arose from such a poetic reflection, but this would be to omit the entire first year of this thesis.

This research originated from the idea of designing textiles that could help female-identifying individuals recover from sexual violence-related trauma. Rapidly, questions emerged: How? What type of textiles? In what context? In this proposal, such a cloth had been coined the term 'emotionally intelligent textile'. Written without the knowledge of its potential meaning, it came to mind that the concept could have some form of value. Technically, because textiles do not have a brain, they cannot *be* emotionally intelligent. Likewise, 'emotional intelligence' and 'intelligent textiles' are two distinct notions, which don't seem to share commonalities. However, as the term 'intelligent' appeared both concepts, in 'emotional intelligence' and 'intelligent textiles', grammar originally questioned whether the notion of intelligence could bridge the two concepts together. Aiming to highlight their similarities and differences, if any, the study investigated them separately and together. Research found that context makes both concepts meet and diverge. This means that, as networks of systems, they are able — emotional intelligence, i.e the brain — or have the ability — intelligent textiles, i.e. "material systems" (Tandler, 2016, p. 36) — to react, perform, and adapt to the environment in which they interact (Salovey & Mayer, 1990; Barman, et al., 2022). However, the former can function in multiple environments without changing its anatomy, while the latter can only perform in one environment at a time. Its structure configuration needs to change from application to application. The idea of 'emotionally intelligent textiles' isn't furthered beyond this introduction. This is because, while its exploration led to refining the research's focus, it isn't, by any means, the scope of the study.

Explored alongside, textile theory enlivened the research; in particular, the tacit knowledge required to create, design, make cloth (Albers, 1944; Dormer, 1994; Igoe, 2011). In an essay[1] (Fourquier, 2022), I conceptually explored how the empty spaces neighbouring warp and weft could be interstitial sites of exchange where the experience, memory and 'quiet' knowledge of the weaver might reside. The essay suggested that empty space might have value in woven cloth. While unintentional, it was the genesis of a reflection on weaving as a discipline and allowed me to find inspiration outside of design research.

The notion of knowledge needed investigating. Thus, in-depth research into emotional intelligence and intelligence (chapter 03) presented the latter as separate to knowledge. As Ceci (1996) outlines, knowledge would refer to a skill coming from previously acquired information and intelligence would relate to the ability to use that skill. In design, emotional intelligence is often considered a gimmick and, albeit explored, never outwardly stated in art or craft. Many have criticised and condemned its validity as an intelligence (Locke, 2005). And, for accounts promoting its potency (Salovey and Mayer, 1990), it has not been seen as a potentially useful attitude outside of humanities. Chapter 03 focuses on knowledge that has to do with practical experience and an intuitive understanding of how things come into being (Polanyi, 1966) — here relating to the maker's emotionally intelligent attitudes. As a trained weaver, the discipline of weaving was therefore an evident choice to explore how weave structure notation is currently understood. But before introducing the focus of this thesis, and the reasons for taking this line of inquiry, let us briefly go back in time.

When I first learnt how to weave, I couldn't comprehend how, on paper, black and white squares signify a specific action on the loom. I understood the grid notation as a checkerboard in which coloured squares' formation illustrate complex but aesthetically pleasing patterns but, I did not grasp how such codes indicate threads' pattern of interlacement. A month into my Master, having no recollection of how I had translated the notation into woven textiles, I had made ten different textiles showcasing structures from the simplest plain weave to the complex taqueté. Somehow, there was a form of intuitive knowledge that my hands as an embroiderer and therefore textile surface manipulator, had acquired before. After all, undoing woven cloth and re-weaving yarns into the orthogonal mesh, had been what had initially sparked my fascination into weaving. This practice had helped me realise that a very simple under/over mechanism can generate infinite complex woven designs. A year went by before the nebulosity of weaving

[1] Essay presented at Textures of Emotions: Storytelling and Textiles, 1st Global Inclusive Interdisciplinary Conference, Athens, Greece, July 2022. No publication.

principles, which had clouded my ability to design, lifted. Then, I realised that graph paper notation is written for the machine to function. In simple terms, it does not tell one how the ensuing cloth will *be* or what it will *do*. From that point everything weaving became an evidence and extensive experimentation grew technical knowledge and practical skills rapidly. Now, my understanding of weave structure notation is innate and as an experienced weaver, I can solve weaving problems. One might therefore ask, why the need for another way of understanding weave structure notation?

Current weave structure notation does not visually indicate technical properties (e.g. drape, function), aesthetic qualities (e.g. pattern, texture) or assembly principles of woven textiles, in that the binary model of coloured squares is only suitable to machine specifications. Today, for established weavers, the understanding of this system of symbol is innate. Thanks to their explicit and implicit know-how of fashioning weave architectures, they are able to create complex designs. Outside of the discipline however, others (e.g. non-weavers, architects, biologists) cannot make sense of such notation and would only be able to mechanically execute what the machine can do. This is an issue because weaving knowledge is reduced to manufacturing tool, which fosters rigid and linear ways of making that are limited to industrial outlooks. To put it simply, all the prior-to-weaving, intuitive, experiential know-how, the 'hidden', is lost. Such knowledge goes beyond one's cognitive ability to use automata. The research proposes that it has to do with the emotionally intelligent attitudes the doer uses to overcome creative and technical problems (chapter 03). This means that such a way of apprehending creation isn't functional but innate and practised (Polanyi, 1966). Additionally, some attest that emotional intelligence is a part of a system of multiple intelligences (e.g. cognitive, kinesthetic). It is only their interconnectedness, and thus their relationship to the whole system, i.e. brain, that can explain their individual need and function — hence allowing humans to *be* and to *do*. This holistic characteristic fed the perspective through which weave structure visualisation was approached. That is to say, as whole material systems, woven textiles require a perpendicular matrix of threads and the aforementioned empty areas adjoining them to exist. Or else, woven cloth would be a mere accumulation of verticals and horizontals. While this remark is applicable for other textile constructs such as knitting, knotting or braiding (chapter 03), this thesis focuses on the structure of woven textiles and their construction methodology. As a result, adopting a holistic approach to weave structure visualisation allowed framing the perspective of research. That is to say, 'empty' spaces might also have value in the visualisation of weave geometries.

1.1 Aims

While a single account, that of Tandler (2016), has explored the potential role of negative space in the construction of auxetic weave geometries, none has ever considered its possible relevance and part in weave structure visualisation. A practice-led methodology and experimental qualitative study framed the research into practical experiments and allowed an interplay between methods: namely, weaving, drawing, microscopy, X-Ray CT scanning, documented through reflective writing. The research aims are as follows:

(1) **Explore weave structure visualisation through the lens of negative space**, in order to underpin the meaning of negative space as a practical tool (chapter 05). Chapter 04 conceptually investigates the idea of negative space as a 'material' space and an inherent component of a weave structure (Ingold, 2010, 2015, 2017). Research into fractal geometry (Mandelbrot, 1975) and the concept of negative space as a support-space in architecture (Kent Peterson, 1980; López-Marcos, 2017) outline the potential of the hole's chaotic, irregular and unpredictable nature.

(2) **Develop a new way of visualising weave structure** by using negative space as a tool to uncover its potential role and value. This was practically explored through weaving, drawing, microscopy, and X-ray CT scanning in the form of two case studies in chapter 05. In order to identify, observe and locate negative space, early experimental studies investigated it as a 'structure unit', and then through the 'repeat' because repetition is a fundamental parameter of weaving.

(3) **Illustrate an ensuing weave structure visualisation** — one that challenges the current notation's binary model by investigating weave structure visualisation through tonality. Chapter 06 explores what grey nuances can uncover about occupied and empty space's relationship.

(4) **Outline the potential benefits of the proposed symbolic system**. In a fourth case study, the visualisation was presented to professionals from outside the textile research landscape. Individuals specialising in multi-species material research, design research, material science and art history, geometric art and material engineering were

invited to take part in a seminar. This aimed to gather non-weavers' insights into the proposed visualisation in order to understand its legitimacy and potential relevance out side the textile research landscape (chapter 07).

1.2 Originality

The distinctiveness of the research is manifested in practice. It proposes that tonality, i.e. grey nuances, enables understanding weave structure as a complex network of antagonistic yet interconnected systems, that is occupied and empty space. The holistic perspective the research takes to visualise the 'unseen', prioritises tacit ways of making. Facilitating creative intervention and thinking through making, this approach thus enables seeing weave structure notation as a craft tool instead of a manufacturing tool. This is pertinent in regards to the current research landscape across weaving, textile design and other creative disciplines. With the rise of biological computation and self-assembly systems, professionals are having to rethink the ways in which things are designed and made. This could have significant impact on the development of new economic models and future production processes that favor localised outlook (chapter 08).

The originality of this thesis also stems from the artistic and craftsmanship standpoint the study takes, both theoretical and practical. Research is not about woven textiles themselves. Rather, it is a research for weaving. Because the functional is not the focus of the study, stepping away from weaving's engineering methodology allows research to embrace the craft's complexity and antithetical nature. This is not to suggest that craft weaving and mechanical weaving are strictly divided. Instead, they contrast in how weaving know-how is gained, and how one might influence or benefit the other. In turn, it evinces the discipline's potential impact and value within interdisciplinary research.

1.3 Contribution to knowledge

The research's conclusions and contribution to knowledge are:

(i) **An illustration of weave structure that questions the binary model** on which the modern weave structure notation is founded. The use of greyness in the visualisation developed enables tonality to act as an intermediary between empty and occupied space and visualise their coexistence and interdependence. Drawing in grey nuances depicts the symbiotic relationship of the two opposite yet interconnected systems as part of a complete weave structure. This is relevant in regards to developing non-binary modes of making and thinking that stem from binary models

(ii) **A proposal of an alternative visualisation of weave structure** that seeks to depict non-mechanical elements within weave structure construction. Highlighting a more holistic understanding of weaving construction methodology could contribute to possible future textiles assembly processes within the physical and digital worlds.

(iii) **Evidence of negative space's role and value** in the visualisation of weave structure. Negative space is a material component — one in a different physical condition than that of yarns — that repeats itself in irregular ways. By questioning the fundamental principles of weaving construction methods, this research could encourage the potential development of novel textile assembly processes.

(iv) **Understanding the holistic relationship of the woven 'hole' to the 'whole'** (weave structure). Central to the research, the notion of w(hole) proposes that the hole is both part and a part of weave structure. This unique perspective was enabled by including emotional intelligence within the research's conceptual framework.

(v) **Understanding X-Ray CT scan as a tool to bridge between disciplines.** The method broadcasts the benefits and possibilities of tonality to visualise weave structure. In parallel, drawings in grey nuances reveal that weave structure visualisation could provide another way of interpreting X-Ray imaging. This in turn could provide a basis for alternative ways of analysing and communicating data both in weaving and other disciplines.

(vi) **Opening up weaving specialism to interdisciplinary research.** The alternative perspective on weave structure visualisation permits untying weaving from manufacturing principles. This emphasises the importance of tacit knowledge and renders a long-established closed up discipline more transparent. Such a standpoint can provide space where others can engage with the craft in innovative ways through interdisciplinary research.

02.

Methodology

02. Methodology

This thesis is governed by a practice-led methodology. The forthcoming chapter examines the elements which, throughout the study, have shaped the development of an alternative weave structure visualisation. It outlines the methodological framework employed, which was informed by a 'make-think' approach. Discussing the findings was an integral part of the research methodology as it enabled practical developments. For this reason, it is interspersed throughout the thesis at the end of each case study and then thoroughly developed in chapter 08. Through a conceptual discourse on negative space, which informs understanding it as a practical tool, this research seeks to explore empty space's potential role and value in weave geometries, in order to propose an alternative, more holistic way to understanding woven cloth construction and properties.

2.1 Way of making and way of thinking

Since its inception, weaving has played a foundational role in our world. The craft distinguishes itself from other forms of textile construction methodologies in the ways that its impliable linear construct shapes not only a soft, fluid cloth, behaving in its own specific ways, but also a planar three-dimensional surface. Yet, this antithetical nature (Albers, 1946; Pajączkowska, 2015) continues to pose questions. As the foundation of Ancient Greek political institutions, architecture engineering and philosophical thinking, the craft goes beyond its mechanical tenets (Scheid and Svenbro, 1996). Both assembly process and structural framework, weaving and thus woven cloth impart the fabric for cultural, political, social, domestic and creative matters to meet (Ahmed, 2004 cited in Golda, 2019). It is therefore as much a way of thinking as it is a way of making — a notion applicable equally applicable to the discipline as it is to other craft such as pottery or wood-working.

The inherent paradox of weaving's construct and product could have provoked demand for the craft to be studied further. However, its notation seems to prompt an urge for deeper consideration. Truly, the pliability/rigidity contradiction isn't reflected in the checkerboard-like visualisation, itself solely inflexible and static — an observation which, to date, has not been explored. Instead, ever since the period of Industrialisation during the eighteenth-century, science has incessantly clung to "the dream of symmetry" (Pajaczkowska, 2005), hence Cartesian modes of thinking eventually imposed the Euclidean grid to weave structure notation, still employed to date.

Additionally, weaving's engineering methodology has inspired multiple fields from architecture (Semper, 1989) to linguistics (Mitchell, 1997; Barnett, 2009; Pajączkowska, 2015; Igoe, 2010, 2021) and computer science (Plant, 1997). Yet its notation remains difficult to understand for non-weavers and therefore uninspiring to professionals practising outside of the weaving realm.

Although weaving is the focus of this research, it is important to note that other textile construction methodologies exist and require a brief overview. The contradiction, stated above, that weaving embodies — rigid construction principles that produce fluid woven textiles — isn't reflected in the fabric structures of other main textile techniques, including knitting and lace making. Similar to weaving, the structure of knitted fabrics is based on the repetitive formation of interlinked loops. While it isn't uncommon for knitting to employ multiple yarns for creating cloth, originally knitted textiles have been constructed with a single yarn — a principle that distinguishes the two processes. Lace making includes various techniques such as, interlacing, interweaving or twisting yarns together. Bobbin lace for instance is, like weaving, constructed with two sets of warp and weft yarns. However, here, the warp yarns are as much in motion as the weft yarns, which differentiates lace structures construction methodology from that of weaving. Contrary to weaving, whose orthogonal construct produces a flexible cloth, the engineering principles of knitting and lace making are more aligned with the characteristics of the cloth that they produce, that which are, similar to woven textiles, soft and fluid. This differentiation is echoed in the notation of knitted and lace textile structures, which are visually more instructive than the one of weaving (chapter 03, section 3.3.3).

2.2 A holistic approach to weave structure visualisation

The manufacture of textiles requires an extensive knowledge of techniques, structures and materials, which according to Igoe (2010), once implicitly or explicitly learnt, become innate. In other words, once "one way of doing" is acquired, professionals tend to abide by this knowledge for the remainder of their lives, "until a "better" way presents itself [...]" (Salustri and Rogers, 2008, quoted in Igoe, 2010, p. 3).

In design, "A discipline requires 'discipline'" (Igoe, 2010, p. 3), in that a specific set of rules needs to be followed by the maker-designer. Yet, their experiential knowledge is equally crucial to the development of new designs and new perspectives on the discipline (Albers, 1944; Polanyi, 1966; Igoe, 2010). This study follows the experiential, tacit attitudes of the maker-researcher paired with their cognitive abilities to generate new ideas (chapter 03, section 3.4). Drawing on eight years of practical experience as a weaver, my own intuitive observations initiated the research and helped create a repository of negative spaces through leno weaving. In effect, research was approached from a comprehensive mindset towards practical experiments — one where experiential knowledge and acquired skills are interconnected.

However, experiential knowledge isn't the framework through which the research was conducted. Rather it is a part of a wider system of procedure — one in which intuition alone would prevent the maker from finding new ways of doing things (Igoe, 2010). As the discipline of weaving shapes the initial understanding of negative space in weave structures, the craft is employed as a practical objective blueprint, inherent to the unfolding of research. Specifically, the technique of leno, also kown as gauze weaving, was employed because it is a technique that facilitates the creation of holes while maintaining homogeneity and stability throughout the cloth (section 2.6.1).

2.3 Practice-led research — a 'make-think' approach

The thesis is governed by a practice-led methodology. Nimkulrat (2012) argues that the practice of craft shapes the anatomy of practice-led research and steers its process. Such a methodological framework facilitates the interplay between the researcher-practitioner's making processes and their reflective, theoretical thinking (Nimkulrat, 2007). In this practice-led research, making processes frame the research while also acting as instruments for conceptual thinking. In effect, the development of the study is heavily influenced by theoretical research. It serves as a groundwork for a practical inquiry, but isn't the main source of data excavation. Hence the choice to use practice as the nexus of this thesis.

Practice imparts crucial documentation to support the research's outcome(s) (Niedderer and Roworth-Stokes, 2007). Nimkulrat (2007) adds that the 'make-think' interplay can be used as "material" documentation (p. 1). This means that making induces reflecting on making processes, themselves imparting critical insights. For instance, T'ai Smith (2014) reveals that, at the Bauhaus, the heart of conceptual thinking was the practice of weaving. Additionally, Guiliana Bruno (2014, cited in Dormor, 2020), albeit writing about other practices than textiles solely, explores how interaction in-between materials originates from texture and the material state(s) of surfaces upon creation. This way of thinking about cloth imparted valuable insights as to how to approach negative space as a 'material' surface. That is to say, one in a different material condition than the one of warp and weft (chapter 04).

Within the broader textile landscape, many textile practitioners have used their practice as a way of thinking, henceforth developing and/or contributing to textile thinking methodologies. For instance, Catherine Dormor's idea of seaming as a (textile) making practice and thinking methodology provides a 'make-think' model in which "practice and theory, practice and practice, and theory and theory come together" (Dormor 2012, quoted in Huang, 2023, p. 153). This attitude proposes that practice-led research isn't an explicit and systematic journey, meaning that order and hierarchy are dissolved in the process (Huang, 2023). The maker-researcher therefore constantly and unevenly oscillates between making and thinking.

This way of approaching research correlates with the making process of weaving, in that, throughout woven cloth's creation, weavers not only pause to reflect on patterns and structures as cloth appears, but also to correct potential mistakes, such as yarn breakage. These un-/mechanical moments are natural instances in the creation of woven cloth and essential to the process because they allow the weaver to ideate new designs — potentially setting forth other ways of thinking about their discipline. This is reflected by Dormor's (2018) conceptual thinking on warp and weft's pattern of interlacement. She points out that weaving is "a mode for thinking that is not *about* weaving, but one that *emerges* within its structures and processes" (p. 126). Notably, through weaving I was able to rethink my abiding understanding of weave structures and their notation.

2.4 Experimental qualitative approach

Practice was guided by an experimental qualitative approach, in that interpretation and induction conduct the initial line of inquiry. Denzin and Lincoln (2005) propose that

> Qualitative research is multimethod in focus, involving an interpretative, naturalistic approach to its subject matter. [...] qualitative researchers study things in their natural settings, attempting to make sense of, or interpret, phenomena [...] (p. 2).

Different methods, namely weaving, drawing, microscopy and X-Ray Computed Tomography (CT) scanning, facilitated an observation of negative space in its 'natural' environment, that is within weave structure, in order to interpret its technical characteristics (chapter 05). Other accounts identify qualitative research as a ceaseless interplay between collected data, theories and findings (Becker, 1963; Aspers & Corte, 2019). This substantiates the use of a practice-led research methodology, because different making processes were blended to dynamically join with concepts and practical evidence — between induction and deduction.

Denzin and Lincoln (2000) explain that qualitative research allows evolution and reshaping of the study. This is permitted through interlacing and progressively involving new tools, methods, and representational and interpretational techniques. The study began with weaving as it enabled the creation of 'empty' space. New tools were introduced, namely pen, paper, microscope and X-Ray CT scanner to decipher the complexity of negative space, bringing rigour, breadth and depth to the research (Becker, 1998). Interweaving the methods uncovered new findings, enabling the research to use negative space as a tool to study weave structure instead of being the object of study (chapter 04).

2.5 Underpinning research outside of the field of design research

Textile practice positions itself at the junction of art, craft and design. In that, all converge towards making, creating, designing. Textile is in turn, simultaneously design process, art practice and craftsmanship. Both textile designers and practitioners use engineering tools and methodologies that stem from their experiential and tacit understanding of the craft (Igoe, 2010; Tandler, 2016). They diverge in the purpose that they serve. The former is mechanical, the latter is artistic.

Truly, textile design research permits designers to produce outstanding and innovative textile materials — e.g. Hydroweave project (Eichler and Neyenhuys, 2020) — evolve the traditional use of machines — e.g. miniature nail loom (Drews, McQuillan and Mosse, 2023) — and develop new making processes for a more responsible future — e.g. zero-waste weaving (Voorwinden, 2023-present). Yet such research is driven by mechanical parameters, and designers actively rely on tangible tools, including automata and digital softwares to solve design problems.

The thesis builds on theoretical knowledge within the textile and material research realm, including thinking through making (Igoe, 2011; Dormor, 2020; Nimkulrat, 2007, 2012, 2025) and weaving as a way of making and thinking (Albers, 1946). This allowed establishing a conversation between theoretical readings and material-driven experimental studies in order to adopt a holistic perspective on weave structure construction and hence visualisation. Weaving's antithetical nature (Pajaczkowska, 2005) and the difference between material and materiality (Ingold, 2007, 2017), allow interlacing studio practice with reflection on the craft's technique and understanding negative space as a surface-interface (chapter 04 and 08). Martin Heidegger's (1954) 'logic of technē' and Walter Benjamin's (1936) philosophy on the dynamic and changeable nature of tradition proceed to question the role of the machine, its impact and constraint on weaving's ancestral practices and the limitations that the current notation's entanglement to automata brings (chapter 03). Finally, Klee's (1921-1931) reflection on the hand's agency v and Berger's (1987) notion of drawing as discovery help interpret the development of the weave structure visualisation throughout the experimental case studies (chapter 05 and 06).

Both following a thinking through making paradigm, craft and design research are linked through making process and its ensuing product (Groth and Nimlkurat, 2025). In comparison with traditional craft methods that focus on the conversations generated from maker/material relationship, designers begin their process with the forthcoming object in mind, not with the material and the infinite of creative possibilities it offers. Thus stepping out and away from design research allows decentering the product and its predetermined use and need from studio practice. Pre-experimentation, the value of negative space within weave structure was believed to be structural stability. But the hole's true influence as a tool to understand weave structure visualisation alternatively and develop a new way of thinking for weaving is only manifested in the final experiments (chapter 06). This means that it is the interaction with empty space, its possibilities and limitations throughout practical experiments that unfold the research.

As a thinking tool, Kimbell (2011, p. 286) proposes that design thinking "privileges the designer as the main agent in designing" and prioritises problem-solving (Nimkulrat, 2025). Here, the need for another way of understanding weave structure visualisation isn't driven by such a model, because the current notational system does not need fixing. Yet, because it is the ways in which the material — here negative space — converse with the maker that leads practical and conceptual development, breaking away from a human-centred way of doing and a product-focused way of thinking was needed.

Brinck (2025) differentiates design thinking from craft thinking. Whereas the former is related to predetermined use and possible benefit of a made product, the latter's primary focus relies on the potential of the materials. Referring to the hand's relationship with materials, the author asserts that "craft thinking is intelligent, not intellectual" (p. 31). In effect, embracing (emotionally) intelligent attitudes enables theoretically delving into the uncertainty of the 'unseen' (chapter 03). That is to say what doesn't attract attention but once identified, becomes conspicuous. In addition to imparting another way of looking at weave structure notation, visualising the 'unseen' as a methodological framework asks: Does negative space serve any other purpose than maintaining a woven matrix's stability? If so, what and who can it benefit within and beyond the weaving realm? From an educational standpoint, it could allow novice and non-weavers to approach, apprehend and learn the craft's construction principles in alternative ways. Likewise, outside of weaving such a methodology could help identify the overlooked and underexplored areas within one's creative practice — opening up a space for innovative material engagement.

Analysis of philosophical scholarship within and outside of textile theory joins with each method employed — in turn allowing the researcher to shift position throughout the study, namely weaver, drawer, thinker, observer. Instead of following the rigid construction methodos to which weaving — as a design discipline — abides, research adheres to a rhizomatic approach (Tandler, 2018). That is to say, one that isn't limited to a discipline's design principles and hence limiting, but embraces "freedom of thought and conception of new ideas" (p. 3). As a result, art and craft practices appear to provide nuances in textile research because they acknowledge and encompass fluid and organic ways of making and thinking that design research at times fails to follow.

2.6 Practice

The study consists of three experimental case studies (i, ii and iii) and a fourth (iv) one in the shape of a seminar aiming at exploring how others, outside of the discipline interpret the proposed weave structure visualisation. Case studies (i) and (ii) are presented in chapter 05. Case study (i) aims to identify negative space as a weave 'structure unit', observe and visualise its geometry. It is followed by case study (ii) which explores the ways in which the shape repeats itself — aiming to challenge the present conception of the 'repeat' in weaving. This enabled a discussion as to whether weave structures can be understood beyond the notion of repetition — a foundational parameter of weaving. Case study (iii) explores tonality as a means to visualise the occupied and empty space's apparent synergy through grey nuances (chapter 06). Finally, case study (iv) aims to examine the ways in which others perceive the alternative weave structure visualisation proposed. Orchestrated through an online seminar, participants from backgrounds outside of weaving were invited to engage in a critical discussion (chapter 07).

A library of woven samples was created to develop a technical database of negative spaces, enabling a reflection on the limitations and restrictions weavers presently face physically, cognitively and emotionally in regards to translating weave structure notation from graph paper to machine. Initial drawings identified specific pictorial characteristics of negative space from sample to sample and within each sample. Alongside, digital methods pictured well-defined negative shapes (microscopy) and X-Ray CT scans broadcasted a moving image of weave structures in grey nuances.

2.6.1 Leno weaving — the establishment of the research blueprint

Among a myriad of weave structures and techniques, leno weaving process — producing leno or gauze fabrics — is meaningful because of its capacity to create well-defined 'empty' spaces within weave structures, while maintaining uniformity, stability and strength "even under a degree of pressure" (Watson, 1913, p. 207). The technique doesn't follow a rectilinear pattern of interlacement. Instead, the threads' set up makes two or more warp threads twist around each other, oscillating from side to side, hence causing each thread to move away from its original position (Emery, 1966). This action disturbs the uniformity of the weave skeleton and creates an undulating pattern-like structure (image 2.1, p. 19). The twisting action is an interaction that the author describes as being informed "by the process rather than by the finished structure" (p. 181).

Likewise, depending on various parameters (e.g. yarn properties, structure design) the gaps' size and shape change.

A library of leno weaves formed a wide lexicon of 'empty' shapes, allowing a categorisation of 'alike' figures. Each was studied under various scales and dimensions.

Scale was a pivotal element for understanding the value of negative space within weave structures.

- The macroscale enabled grouping of negative spaces in types, namely, 'squares', 'triangles', 'other shapes'.
- The microscale brought accuracy to the research, because variation of form could be identified.
- The nanoscale engaged a reflection on colour in the visualisation of weave structure. It also interrogated the idea of repetition because occupied and empty space appeared amalgamated into a single system of shapes.

Dimension was crucial to the study because it provided insights in regards to the role of negative space in weave structure visualisation as well as initial drawings' limitations, which remained partly subjective and intuitive (section 2.7.2).

- 1D presented the limitation of only drawing negative space's outline.
- 2D visualised negative space as a solid form but overlooked the idea of depth. Even though, as a hollow shape, negative space is lacking a front and back side and therefore 'depth', warp and weft's density provide it with a potential width.
- 3D identified negative space in-between and within yarns — introducing the possibility of a topology of negative space.

2.6.2 Drawing

Drawing was used because of my experience as a trained drawer. Weavers often diagram weave structures when creating complex cloth. This activity occurs post and during weaving, especially at the sampling stage of making (figure 2.1).

In his treatise on drawing, Klee (1918, cited in Healy, 2022) considers that the hand's movements are dictated by external forces. For Von Sydow (1919, cited in Healy, 2022) Klee realises that

Image 2.1
Photograph of leno weaving showing the ondulating pattern
Ariane Fourquier (2023)

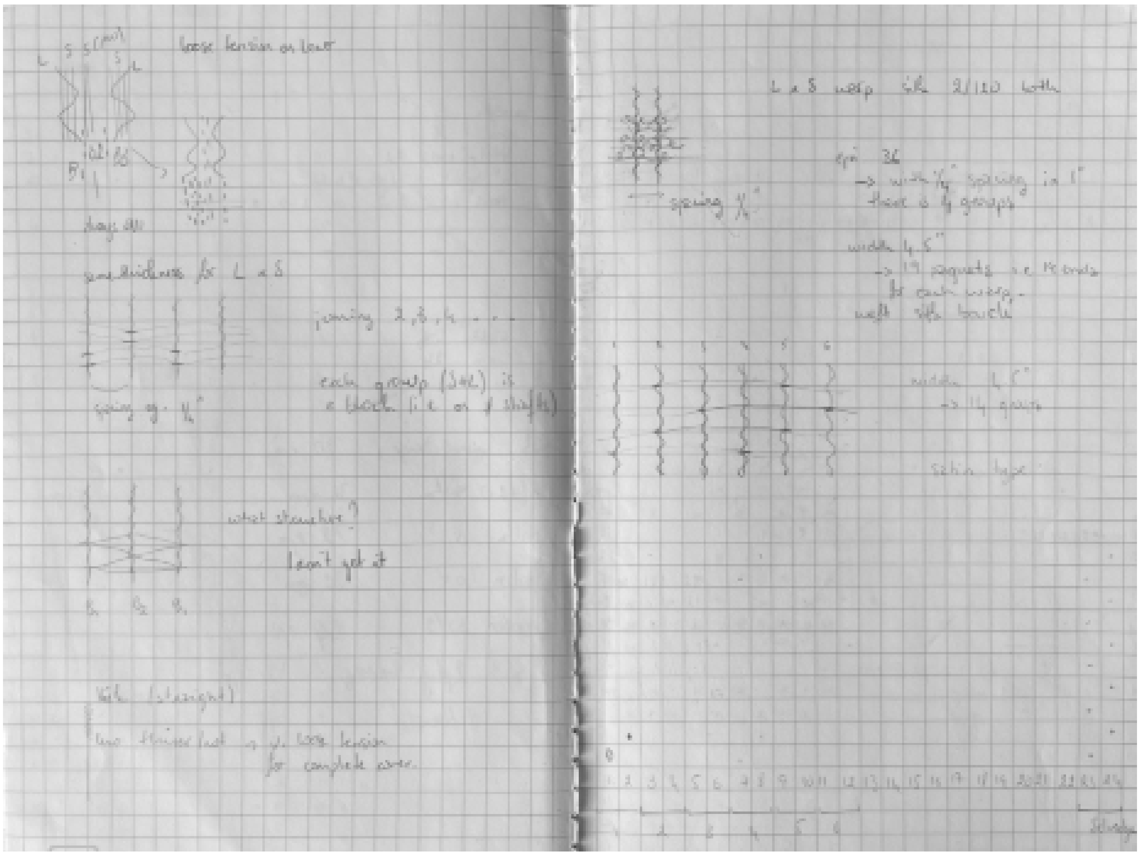


Figure 2.1
Drawings and notes made post and during weaving
Ariane Fourquier (2023)

the drawer's thinking mind isn't accountable for their hand's gestures. This outer energy might belong to hands' tacit know-how and could be manifested through the drawer's intuitive attitudes towards what is being drawn (chapter 03). Hegel's (1807, cited in Riley, 2008) idea of art is interpreted by Riley (2008, pp. 1-2) as a fine equilibrium involving "conceptual intrigue [...] and perceptual intrigue". Respectively steering the viewer towards new insights based on theoretical evidence and offering interpretative experiences thanks to the material attributes of the artwork. Additionally, Berger (1987) proposes that drawing imparts three different purposes, namely "[...] those which study and question the visible, those which put down and communicate ideas, and those from memory" (p. 46). The first purpose interests this thesis particularly because it enables the draughtsman to delve into the peculiarity of the 'unseen' and interrogates the object of study through a back and forth interplay between eye and hand. The second function applies to the alternative weave structure visualisation proposed, in the sense that it enables the viewer to interpret what is being communicated. The third intent aligns with Klee's philosophy of the hands' instrumentality and aptitude to ceaselessly apply line onto paper. It conveys the idea of 'remembering' which, as Klee suggests, is an action independent of the drawers' thinking mind, i.e. memory.

It is noteworthy that objective and subjective drawing divide the method into two attitudes. The former relies on Euclidean geometry and Renaissance's codification of perspective (Ruskin, 1857; Marr, 1982, cited in Riley, 2008). Meaning that it imparts quantification, measurements and empirical analysis. The latter depends on the drawer's experience of drawing. Their interpretation of reality is driven by personal and emotional factors, as well as experiences (James, 1943; Graham, 1997, cited in Riley, 2008). This is not to say that objective drawing is irrelevant. In that objectivity also allows one to represent the material complexity of the object of study.

Studio practice initially drafted separately negative space's outlines and content in order to visualise its periphery and surface treatment, respectively. But, as the research aims to elude mathematically-driven ways of notating cloth's construct and focuses on the maker's creative approach, the drawer's personal interpretations in visualising negative space must be taken into account. These are personal in the sense that artworks dictate the ways in which they are drawn and analysed — not the researcher's personal feelings towards the object drafted. In turn, the hand's freedom imparts inductive evaluation and analysis for research to proceed — leading drawing to adopt a 'subjective' context-dependent attitude both in studio practice and data analysis.

First this facilitated the understanding and depiction of individuality and difference as well as unity and similarities of negative shapes. Second, along with interpretation of X-ray CT scans, it allowed research to reconsider the weaver's default use of black and white. Meaning that the lack of nuances failed to acknowledge fluidity and movement. This evaluation was founded on objective observations of colour use, providing space for drawings to evolve into looser and softer imaging of weave structures in grey tones.

2.6.3 Microscopy

It is important to note that, in this study, drawing and microscopy combine, in that initial drawings (case studies (i) and (ii)) were drafted from microscopies of negative spaces. While the theories drawn on relate to photography, this thesis applies them to microscopy because these are a form of photograph. Photography as a method wasn't employed because negative space needed to be observed at a higher resolution, one that a camera could not provide.

Microscopy is a photograph taken through a microscope device, which is usually employed to observe entities imperceivable to the naked eye. It is an instrument that increases their size, in order to examine extremely small structures at a scale adequate for researchers' analysis.

As Walter Benjamin (1936) writes, "Compared with painting, it is the infinitely more detailed presentation of the situation that gives the performance portrayed on the screen its greater analysability" (p. 28). Although his argument relates to photography, microscopy too, offers considerable accuracy and objectivity of analysis. Nevertheless, some might argue that the degree of objectivity provided by the apparatus through which the object of study is observed is relative. That is to say, the lens stands between the researcher's eyes and their work (chapter 05), hence questioning validity in data analysis. Yet again, the performative nature of the method deepens the interpretation of findings. Although woven cloth is pictured as an inanimate object, microscopy portrays three-dimension, hence offering explicit clues as to its innate characteristics.

2.6.4 X-Ray CT scanning

Computed tomography (CT) is a computerised X-ray imaging technique. X-Rays capture multiple 'pictures' by rotating around the object of study, then translated into cross-sectional computerised images, also known as slices. X-ray CT scan doesn't generate a visually clear image. As such, the method isn't interesting if one wants to distinguish well-defined details. CT scanning is mostly used for quantitative analysis, in that specific mathematical formulas are applied to classify the entity's properties (e.g. density percentage). This is adequate for scientific approach to research and empirical analysis of data, which is not the aim of this study.

Contrary to microscopy, X-ray CT scanning doesn't provide accurate technical data, such as negative space's exact delineation — properties that a powerful microscope would supply. But, the digital rendering enables scrolling through each slice, hence animating the image (chapter 05). This accorded X-ray CT scanning a performative quality, in that empty and occupied space's blended appearance suggested their synergy.

Although the microscopic and nanoscopic methods employed often appear in material engineering, they provide research with an objective perspective on visualising negative space. Yet, these scientific methods still depict the organic and irregular nature of weave structures, parameters that the current notation system rejects. Therefore, alongside weaving and drawing, analysis was made possible both explicitly and implicitly, in order to provide a holistic perspective on weave structure visualisation. An approach that bridges the mechanical and unmechanical, the physical and non-physical, the occupied and vacant space.

2.7 Analysis through observation — embracing the complexity of negative space

Data analysis cannot evade subjectivity. Simply, the drawer's hand cannot escape from its own will, the microscope's lens impacts negative space's natural behaviour and X-ray CT scanning cannot scan airy entities. So how to impart objective judgement?

2.7.1 'Data Humanism'

Acknowledging the worth of subjectivity was essential to the analysis of findings because potential mistakes, inconsistencies and flaws in the data collected should be appreciated. Lupi (2017) coined this procedure as 'Data humanism', an analytic approach that aligns with the holistic attitude adopted to the study of weave structures. Because of the complexity, irregularity and unpredictability of negative space (chapter 04, 05 and 06), a more nuanced approach enabled analysis “at a deeper level” ([no pagination]) — one closer to describing reality.

2.7.2 Observation

Observation is a method mainly employed in ethnographic research for the study of social and cultural phenomena. Crouch and Pearce (2012) explain that it is a strategy allowing researchers to fully immerse themselves in the field of study. It is a technique in which multiple means of doing can be taken. In effect, “Observers may watch, listen, converse, write, draw, film or take photographs” (p. 92). This thesis isn’t a study of human interaction. However, it aims to ascertain the value and potential role of negative space within weave structures. In other words, by observing negative space within weave structure, concrete insights as to its un-/mechanical characteristics were drawn.

As research demanded comparison of negative spaces first between samples, then within each sample, cluster analysis was employed to as it relies on “the criteria of likeness/similarities and differences/contrasts” for the identification of groupings (Gray and Malins, 2004, p. 138). This mode of analysis usually visualises data into ‘clusters’ so that both connection between and specificities within groups can be drawn. While the technique is mainly used to arrange large amounts of data, it is its principles enabled the organisation of negative space into shape-types, namely, squares, triangles and other shapes. Within and across all groups, relationships between empty space were made and their individual specific characteristics were identified (chapter 05).

2.7.3 Reflective writing

Reflective writing implies the critical analysis of an experience, indicates how it impacted the research and the researcher, and narrates what this knowledge can generate. It is a tool to challenge assumptions, as well as being analytical, subjective and adding depth to the inquiry. Reflective practice can be separated into two branches of knowledge generation: reflection-in-action and reflection-on-action. The former occurs at the time of the action. The latter involves the analysis and interpretation of data post-making (Schön, 1983).

An interplay between the two enabled analysis of findings at different stages of the study, in turn letting the research unfold for new results to arise. Case study (i) revealed that:

(1) Line drawing limits the visualisation of negative shape’s borders and overlooks its

surface-content.

(2) Black/white colour use maintains the rigidity of weave structure visualisation from which the study aims to step away.

(3) Weave structure is informed by yarns but is not confined to yarns.

Case study (ii) uncovered that:

(1) Weave structure cannot be notated through 'empty' space nor threads alone, hence confirming the value of negative space within weave structures.

(2) Individuality and similarity are key parameters of negative space, in that it repeats itself in inaccurate ways within a full weave structure.

Research proceeded with an exploration of greyness and what it can uncover about weave structure visualisation. Case study (iii) (chapter 06) unveiled that:

(1) The idea of tonality challenges the black/white binary.

(2) Notating weave structures in grey tones proposes an alternative weave structure visualisation that identifies the interdependence of occupied and empty space.

Finally, the proposed weave structure visualisation was presented to professionals working in different fields than weaving in order to gather others' opinion on the alternative notational system (chapter 07). Case study (iv) identified that:

(1) Opinions diverge regarding the value of grey in weave structure visualisation. Some were confused by what it indicates while others saw it as a bridge between occupied and empty space.

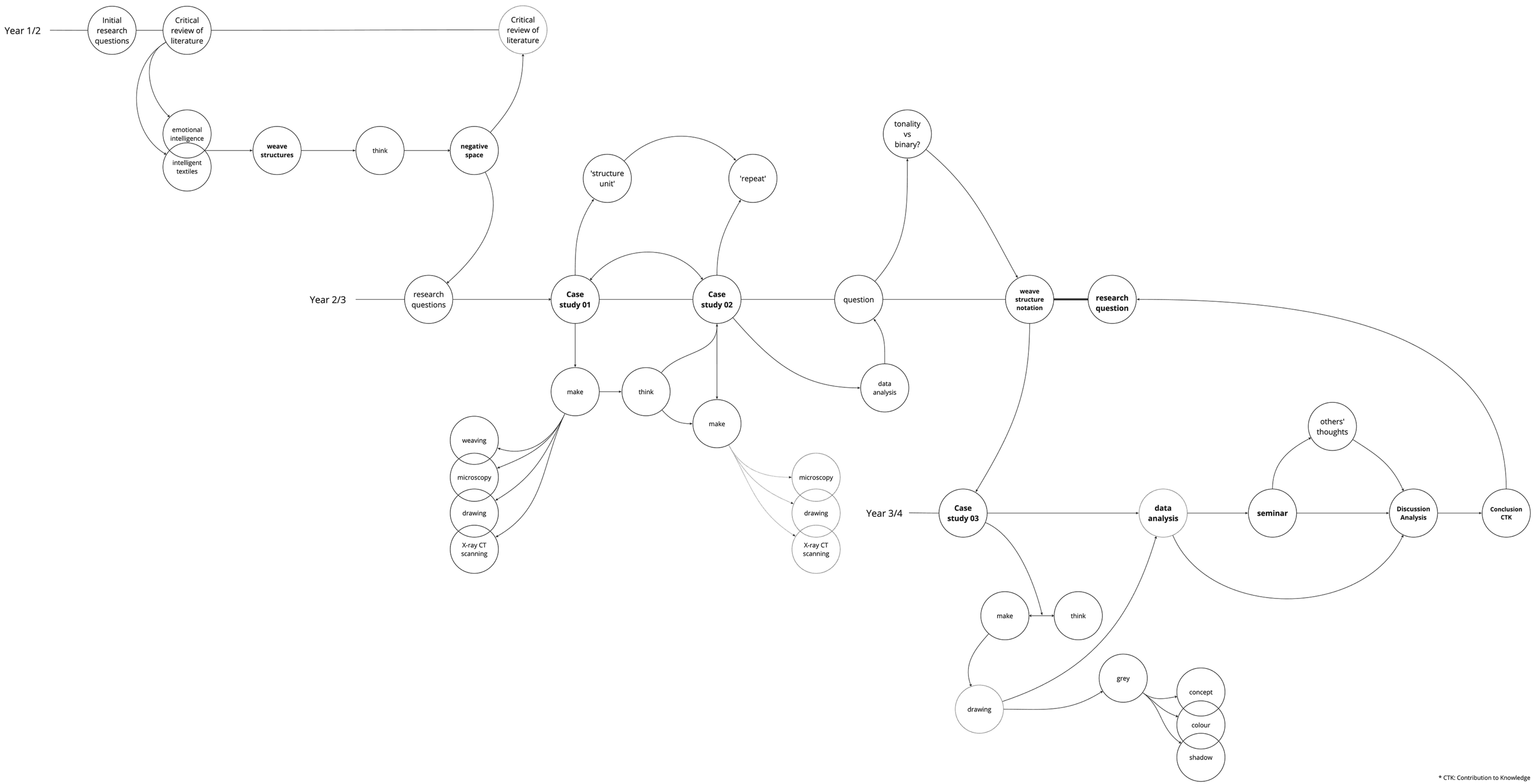
(2) The idea of non-written notation questions the ways in which weaving knowledge is communicated.

(3) The notion of 'agency' proposes to look at empty space as a dynamic space instead of a passive one.

2.7.4 Rhythmanalysis

Theorised by Lefebvre (1992, quoted in McLean, 2019, p. 69), rhythmanalysis questions "issues of change and repetition, identity and difference, contrast and continuity". Although the approach is mostly used in urbanism and humanities to understand the effervescence of lived areas, it relies deeply on practice. This means that it enables analysis to shuttle from "abstract to concrete, from theory to practice" (McLean, 2019, p. 69). In other words, while as an analytical tool, unpredictable insights might emerge, rhythmanalysis fosters oscillation between observation and critical thinking, which, as exposed in this chapter, are key parameters aligned with this research. This method enabled a metronomic attitude to data analysis. That is to say, it is the irregular fluctuation between theory and practice that brought about new insights and shed light on unknown and unpredictable phenomenon. By shaping the development of the proposed visualisation system through tonality, rhythmanalysis enabled a more nuanced approach to weave structure depiction.

Chronological diagram outlining the ‘make-think’ methodological approach of the research



* CTK: Contribution to Knowledge

03.

Systems

03. Systems

Investigating the notation of weave structure requires writing about woven textiles and their construction principles. To weave is to assemble textile elements (e.g. yarns, sticks, strands) together in a grid-like system. The product of this interlacement abides to the orthogonal binding of longitudinal warp threads and transverse weft threads. Warp signifies a set of taut vertical yarns, known as ends and arranged in a parallel formation. Weft denotes the accumulation of successive horizontal yarns, or picks (figure 3.1). This ordered assembly constitutes the structure of woven cloth. Different structures result in different functional and/or aesthetic designs.

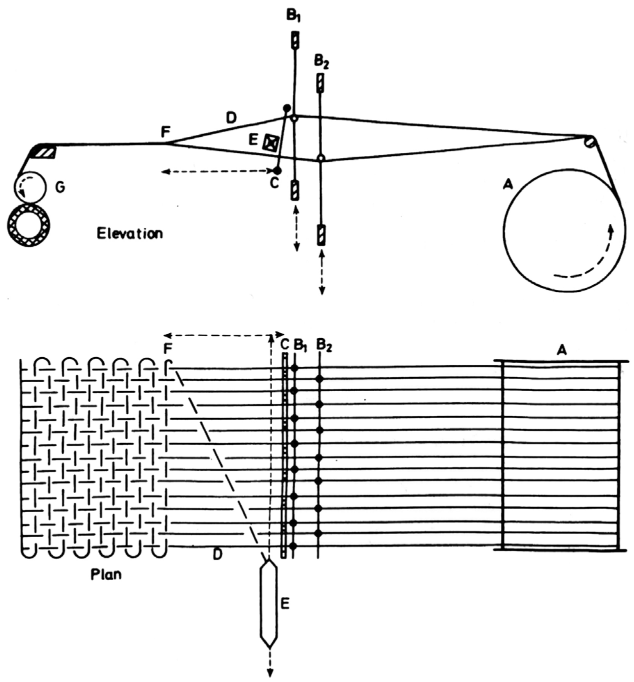


Figure 3.1
Layout of weaving loom, A: Back beam; B1 & B2: shafts; C: Reed; D: Warp yarns; E: Beating Rod; F: weft yarns; G: Back beams
Illustration from Watson (1912, p. 2)

Watson (1912) identifies two principal categories of structures. Simple structures are only composed of one set of warp and weft. Within each set, ends and picks are parallel to one another and together follow a perpendicular formation. Compound structures conform to the same intersecting pattern but may be composed of more than one set of warp and weft, some of which might act as the ground of the fabric, while others remain purely ornamental. This may result in a non-linear formation of elements (e.g. leno weaving). But essentially, weft elements systematically pass over and under one or more warp elements (figure 3.2).

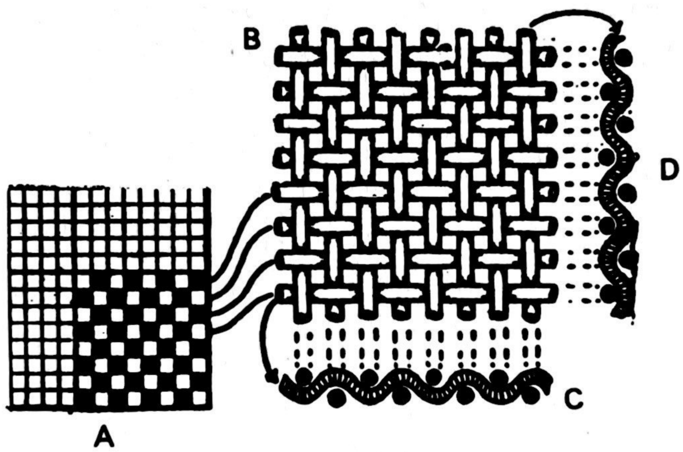


Figure 3.2
Construction of elementary weaves
Illustration from Watson (1912, p. 20)

Weaving's elemental construct, a systematic, hierarchical formation of perpendicular elements, also known as tabbi or plain weave, possibly began 8000 years ago (Barber, 1991). How it began is unknown and will likely remain so (Broudy, 1979, cited in Tandler, 2016). However, going back the craft's potential beginnings might uncover insightful evidence about how weave structure notation is understood.

3.1. System of symbols

A notation is a system of signs or symbols employed to visualise data. Following this definition, the current weave structure notation can be seen as a system, whose symbols are black and white squares. Those indicate warp ends movements on the loom, which allows the under/over passing of weft picks. A system of symbols, also known as a symbolic system, relates to an ordered set of signs, whose structural formation establishes certain rules for individuals and/or machines to interpret different meanings and carry out various functions. These can include written (alphabetical), visual, mathematical languages, and digital codes, among others.

In weaving, there exist three different notation systems or plans; threading plan, lifting plan and weave plan. Respectively, these are graphic visualisations of: the order in which threads are individually threaded through the shafts' heddles on the loom, the lifts of each shaft and, the lift of each warp end on each weft pick, respectively. This thesis focuses on the weave plan because it represents threads' pattern of interlacement, i.e. weave structure — serving the weaving process to create the woven product. The following section chronologically explores the potential origin and evolution of weave structure notation to the modern one.

3.1.1 Traces of weaving

As Tandler (2016) puts it, "The past is often a helpful guide to the future" (p. 72). Yet, precisely identifying the origin of the first weave structure notation can only be speculative. Certainly if prehistoric weavers ever used a notation system, the passing of time has effaced all evidence. Nevertheless, imprints of prehistoric textiles could be seen as one of the first repositories of weave structures for today's researcher. Traces as opposed to notations, they might bring about insights for exploring the current one.

Recent excavations in the Ness of Brodgar, Scotland (2020) for instance, found a textile imprint in a clay pot dating back to the Neolithic Age (10000 BC – 2200 BC). Although ill-defined, the "remnant textile surface" (Davis and Harris, 2023, p. 1) acts as visual evidence of a once existing fabric, i.e. its structure. As Broudy (1979, cited in Tandler, 2016) explains, no impressions on clay have been found prior to the use of the stony material. This means that pre-Neolithic, no account can confirm whether woven cloth existed — let alone its structure visualisation. However, one of the earliest visual representations of humankind dates back to 40,000 years ago. Cavemen, such as the one of El Castillo in Puente Viesgo, Spain, stencilled their hands by spitting pigment on walls, leaving behind their hands' negative image (d'Errico et al., 2016). Thus, visualising was practised long before weaving's inception.

Broudy (1979, quoted in Tandler, 2016) states that "the farther back we go, the less likely it is that fibrous materials would survive" (p. 72). The advent of the Copper (3500-2500 BCE), Bronze (3300-1200 BCE) and Iron (1200 BCE-550 BCE) Age, brought about new metal materials. Chemical reactions between metal's molecular structure with other material elements, offer another type of weave structure traces (image 3.1). Textile conservation researchers Davis and Harris (2023) explain how at interment locations, complete or partial conservation of woven textiles is made thanks to biochemical reactions occurring between metal composition and microorganisms responsible for natural textile materials' decomposition (e.g. cellulose fibre).

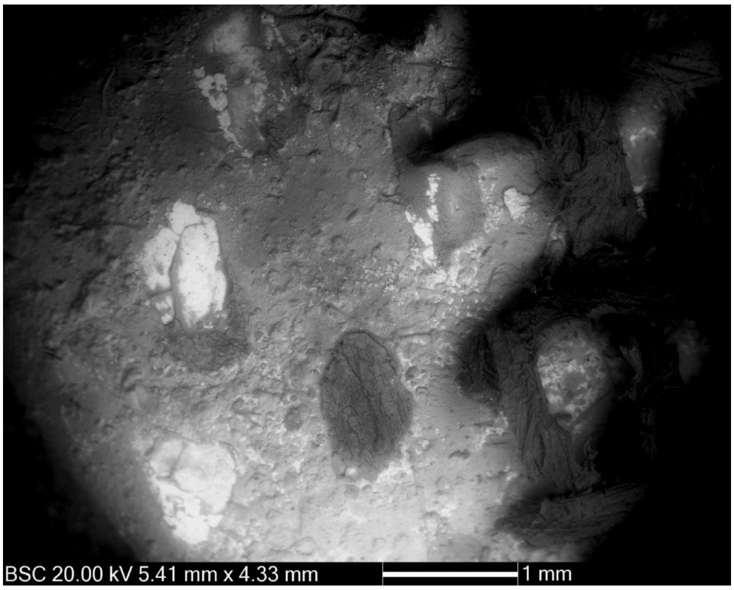


Image 3.1
SEM BSE image of the corroded area on the casing of the composite bead (71.5). The darker petal shapes are surviving organic threads – remnant textile surfaces; the lightest petal shapes are uncorroded silver – ghost textile surfaces
Image from Davis and Harris (2013, p. 9)

Consequently, different forms of archival woven textile material offer various types of weave structure residuals — already questioning how weave structure visualisation is understood.

While these archeological materials show weave structure traces of long gone textiles, they cannot be viewed as notational systems that weavers would have used back then. They solely provide today's researchers with secondary evidence of weave structures, techniques and raw materials then employed to construct cloth. Thus, if no repository of prior-to-weaving knowledge was ever found for prehistoric woven textiles, how did the craft persist? Even more so because throughout time, before the first looms were invented, prehistoric textile imprints evidence that weavers creatively crafted cloths with a variety of weave structures, i.e. "more than one possible way to bind threads together" (Barber, 1991, quoted in Tandler, 2016, p. 72).

Andean woven textiles are some of the most mathematically complex textile systems in the world (Brezine, 2008). They display a rich library of weave variation, which makes evident that startling complex structures were developed and archived without the use of notation systems. Thus, woven textiles were probably the foremost and primary form of structure repository (Harlizius-Klück, 2017). This intuitive way of working therefore allowed for the creation of intricate woven designs without the use of mechanical tools (Broudy, 1979; Albers, 1965). Additionally, because there was no industrial landscape, ancient practices didn't need an industrial script of weave structures. As such, it is most likely that weaving know-how would have been tacitly passed through observing, listening and making from elders.

3.1.2 Algebraic writing

Weaving's construct has always followed a binary language, encompassing parameters such as symmetry, reciprocity, relationality, hierarchy and functionality among others, all of which are demonstrated in primitive weaving. Long before the machine, ancient weavers were tacitly applying algebraic writing to create new structure compositions (Harlizius-Klück, 2017; Brezine, 2008).

Algebra, which stems from the Arabic *al jabr*,[2] meaning 'reunion of broken parts', could be linked to weaving. While the craft isn't exactly the 'reunion of broken parts', it is the union of two or more entities in an orthogonal pattern of interlacement (Watson, 1912; Emery, 1966). Plimpton 322 (circa 1800 BCE) is a Babylonian tablet thought to be an accurate illustration of the Arabic numeral system (Casselman, 2023) (image 3.2). A range of indentations engraved in wet clay pictured a stroke for '1' and a combination of 'broken' marks for numbers '2' to '9'. However, the integer '0' didn't figure in the Babylonians' mathematical lexicon. Rather, it was interpolated, that is, interposed into other digits (ibid.). While being a subjective observation, Plimpton 322 pictorially echoes woven textiles' grid-like structure. Furthering this remark, the craft, albeit binary, might have never considered zero as a complete entity part of woven cloth's matrix. Instead, the number could have been tacitly embedded into other parts (e.g. yarns) (Fourquier, 2024). Once again, as a system of symbols, one could posit that the numeral plate could have been one of the first weave structure visualisation. That is to say, a nexus of thoughtfully assembled lines picturing threads' perpendicular formation.

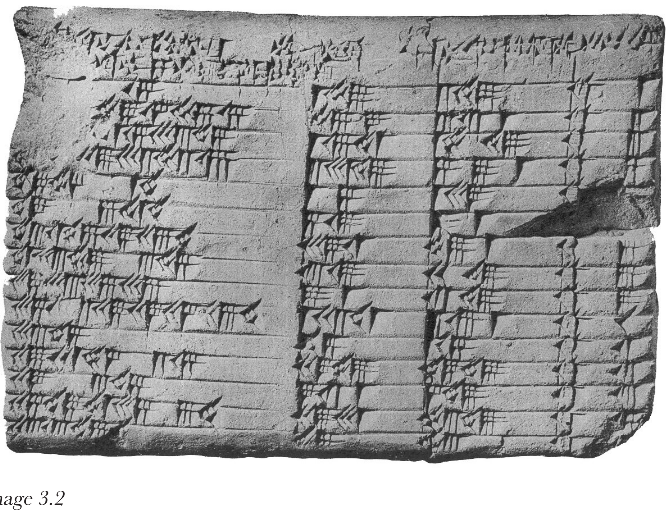


Image 3.2
Plimpton 322
Image from Casselman (2023, [no pagination])

[2] The Arabic الجبر, translated to Latin alphabet as 'al jabr' first appeared in ninth century treatise Al-mukhtasar fi hisab al-jabr wa al-muqabala, translated as The compendium on calculation by restoring and balancing, and written by Persian (Bagdad) mathematician Abu Ja'far Muhammad ibn Musa al-Khwarizmi. 'Al jabr': 'reunion of broken parts, bone-setting' first referred to the preliminary steps to resolving algebraic problems. It then shifted to 'jabara', meaning 'reintegrate, reunite, consolidate and bind together'.

In essence, the intangible bridge between algebra and weaving really exists because of the discipline's parametric nature. Today, algebra is a complex writing system that manipulates variables into formulas in which numbers are replaced by letters. Brezine (2008) states, "All the algebra that weavers did is buried and covered, hidden and misunderstood" (p. 192). The scholar asserts that the mechanical rise and popularisation of the loom resulted in the loss of an ancestral tacitly mathematical form of knowledge. Though, one could argue that this is only true for the visual representation of weave structures that the automated loom requires — first a system of hole formation on paper cards, now a matrix of coloured squares on graph paper.

In fact, recent studies stem from a tacit understanding of weaving's geometric principles. For instance, artist-researcher Gali Cnaani (2023) develops innovative weaving reeds — a comb-link device that beats down every horizontal thread — designed to alter the orthogonal crossing parameter of weave construction (image 3.3). This research confirms that weaving's algebraic tenets — here, orientation control variable — are still tacitly applied to further the textile research landscape.

Other accounts aim to redress weave structure visualisation issues by tending to the current incompatibility of the mechanical with the unmechanical. Pairing the craftsman's experiential knowledge with computational tools, Orynek, Thomas and McKay (2023) use shape grammar, a computational configuration to write with shapes, to create a "weaving grammar" (p. 380). In simple terms, this new visualisation language is a novel way of using signs, yet still informed by a 0/1 binary set of rules. The new visualisation system merely indicates the weaving process, acting as a framework to understand thread movement (figure 3.3). Here the weave structure unit, i.e. one complete repeat, isn't taken into account, failing to indicate the structural topology of woven cloth.

Hauptmann (1952, cited in Harlizius-Klück, 2017) states that currently weave structure notation is nothing else than the "manipulation of symbols" (p. 199). In fact, it is a symbolic system only weavers can comprehend once learnt — one that doesn't explicitly indicate how components are put together. It merely alludes to the potential aesthetics of cloth and signifies threads' movement on the machine. Even then, structure visualisation of techniques such as leno weaving, doesn't inform the weaver as to the resulting pattern and what the cloth can/not do, because it does not identify the warp threads' undulating pattern.

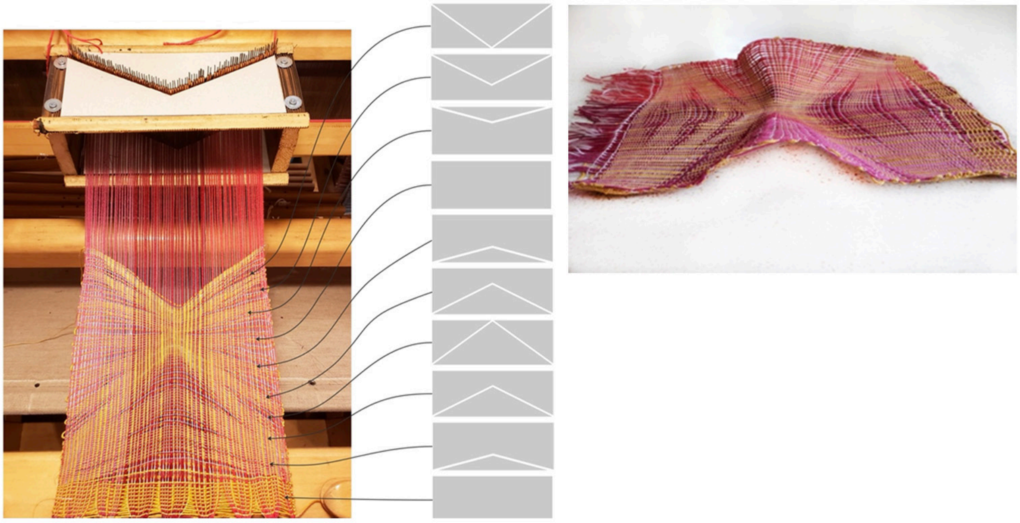


Image 3.3
Left: The woven sample on the loom, and the corresponding stencils used in each part of the weaving. Right: The 3D deformation of the fabric after being removed from the loom
Image from Cnaani and Sterman (2023, p. 7)

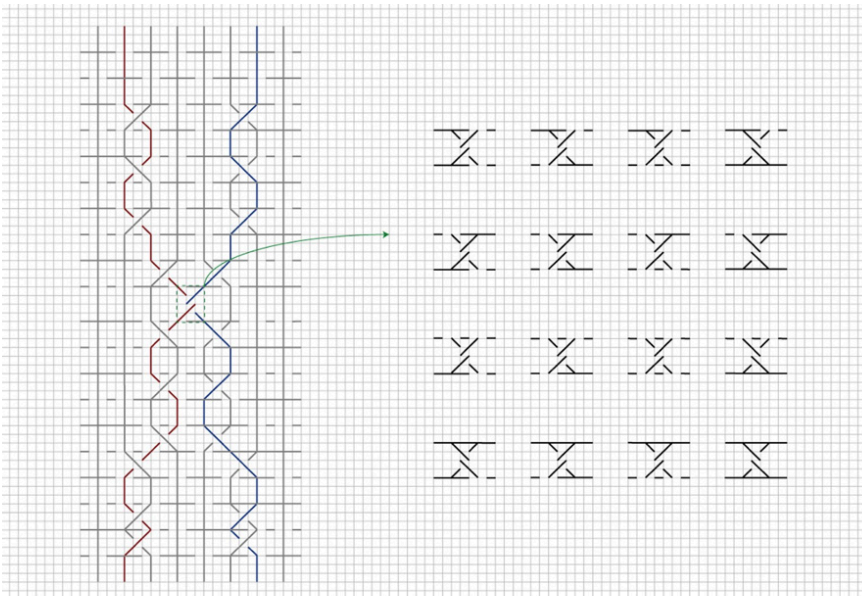


Figure 3.3
Grammar-based notation of the material sample and all possible weftless rule computations
Illustration from Orynek, Thomas and McKay (2023, p. 11)

In *Algebraic expressions in Handwoven textiles*, Ada K. Dietz (1949) notes how she applied algebraic writing to the construct of a threading plan. Using a four shafts handloom, Dietz assigned x to shafts 1 & 2 and y to shafts 3 & 4. She explains that she was able to write a vast array of threading plans as long as there were sufficient shaft combinations to be replaced by x and y (figure 3.4). This allowed her to draw out a multitude of weave structure plans, hence finding that algebra opened up "space for divisions, proportions and individuality of pattern which the artist strives to achieve" (p. 2). While she develops a new system of symbols for threading plans — not one for weave structure notation — Dietz confirms that algebra is embedded in weaving construction methodology. Further, she validates the importance of looking at weaving from other perspectives to contribute to makers' creativity. Consequently, this evidences that an alternative perspective to weave structure visualisation can engender new procedures of thoughts towards the craft's engineering tenets.

$(x + y)^2 = x^2 + 2xy + y^2$ x = 1-2 harnesses for overshot weave
y = 3-4 harnesses

Writing the draft in the usual fashion from right to left, the parts of the equation are:

	x^2 =	2xy =	y^2 =	or all -
	1 1	1 1		1 1 1 1
	2 2	2 2		2 2 2 2
		3 3	3 3	3 3 3 3
		4 4	4 4	4 4 4 4

The pattern may be threaded by continuous repeats
or may be reversed either at the center or at intervals.

Figure 3.4
Algebraic expressions with the square of a binomial
Notes from Dietz (1949, p. 7)

3.1.3 Standardised notation

Currently, weave structures are visualised by a checkerboard-like mesh of coloured squares, usually black and white, in which each square indicates one warp-weft crossing. Black squares identify warp uppermost, white ones picture the opposite (Emery, 1966). The 'pixel-like' notation system, pertaining to a pattern of interweave, is designed to fit automata specifications (Pajączkowska, 2005; Harlizius-Klück, 2017) (figure 3.5). In effect the static drafting model only pictures the systematised formation of yarns on the machine.

Pre-industrialisation, the secrecy of weaving guilds makes it difficult to ascertain when notations were first written (Schneider, 2015). Their apparent need to maintain weaving 'sacred' knowledge, within the workshop's walls, might have locked the craft away from others to reach. Similarly today, weaving is only available to trained and experienced weavers, hindering engagement in the discipline from external research spheres. Nonetheless, in seventeenth-century Germany, handbooks were found in Ulm, depicting different visual schemata than the ones we know today. Some of them picture sets of horizontal lines, much like the staves of a musical score, crossed by sets of straight or zig-zagging lines, at times ending with an ornamental curve (figure 3.6). These notations, alike to Dietz's (1949) algebraic approach, signified the drafting plans a shaft loom necessitated — not weave structure notation itself. Once again, this substantiates that other forms of notation, that is, symbolic systems, offer different perspectives on the craft's principles. However, it also shows that weave structure notation has not been a concern since the First Industrial Revolution (1760-1840), when the thrust towards automation began.

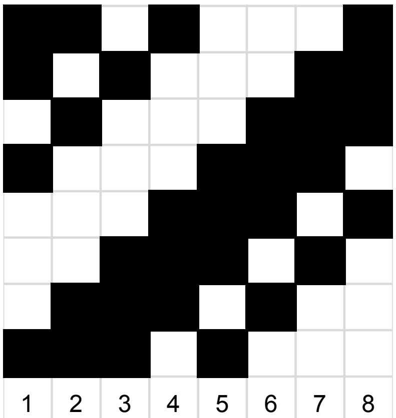


Figure 3.5
3/1/1/3 twill weave structure notation
Ariane Fourquier (2023)

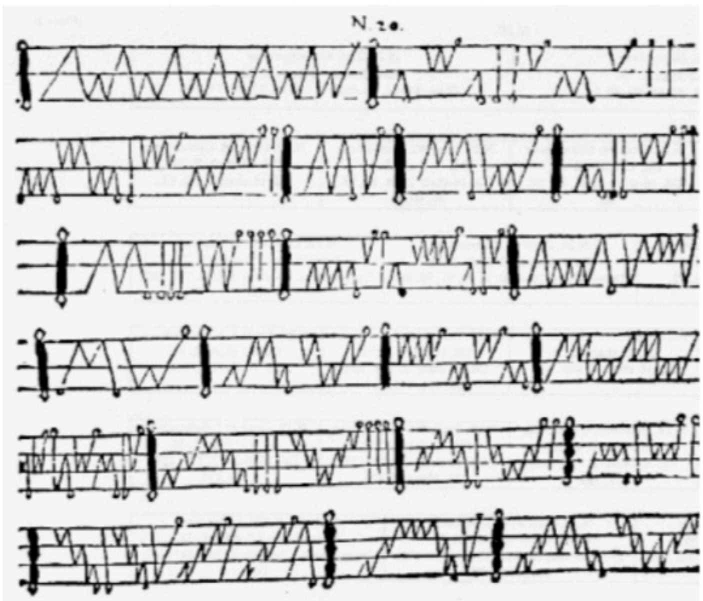


Figure 3.6
Plate containing notations of twenty threadings for the setup of a loom, Ziegler's Weber Kunst und Bild Buch (Ulm, 1677)
Illustration from Schneider (2015, p. 143)

The stave-like schemata indeed provided much more structural variation because it offered a visual clue of threads' pattern of movement. Straight, unwavering lines maintained a static comprehension of weave structures; and while some (Foster, Dunbar and Harper, [no date]) have managed to transcribe it into the modern grid system, it still appears as a complex script both for todays' weavers and non-weavers. Simply, the representation of threads' configuration was already the sole focus.

Charles Sanders Pierce (1903, quoted in Smith, 2017) states that a specific type of symbol notation bears the "skeleton-like sketch of its object in terms of relations between its parts" (p. 242). Smith argues that it relates to something that "essentially details a procedure of thought" (p. 242). However, in the context of her writing, this is true if one thinks through threads only. Albers (1965) states that because over time weave structures became more elaborate through various modifications, their notation necessitated being simplified in order for the industry to create weaves under a conventional framework. As a result, the grid eventually normalised weave structure notation system, that is, the ways in which symbols are formatted.

3.1.4 Automata

The automation mania of industrialisation (1760-1840) has confused many accounts on the notion of technology. Reviewing Becker and Wagner's (1987) book on weaving techniques of Ancient China, Kuhn (1990-1991), affirms that the craft is intricately linked to loom technology, and the discipline's 'art' cannot be separated from it. This unreferenced statement ignores ancient worldwide weaving practices that solely required the maker's tools, that is, their hands, body and at times wooden sticks. Aligned with most accounts, Broudy (1979) proposes that a loom is "any frame or contrivance for holding warp threads parallel to permit the interlacing of the weft at right angles to form a web" (p. 14) (image 3.4). He explains that advancements in loom mechanisms were dependent on the warp's fibre and then yarn properties. The development of spinning techniques and machines initiated the evolution of weaving looms. Standing as primal protagonists, spinners actuated the beginning of industrialisation (Broudy, 1979; Tandler, 2016). On the eve of the First Industrial Revolution, Diderot (1762-1772, quoted in Broudy, 1979) wrote in the Textile Art volume of *L'Encyclopédie*: "Let us at last give the artisan their due" (p. 146) (image 3.5). His attempt to glorify and promote weavers' knowledge and skills pre-process, was, ironically, short-lived as unprecedented mechanical development increased weavers' reliance on automata while lessening their proximity to materials, i.e. yarns. However, weaver's dependency on the loom isn't solely due to loom mechanism improvements. In fact, those generated new techniques of lifting warp ends, including the Jacquard loom's punched card system, and therefore new way of constructing cloth.

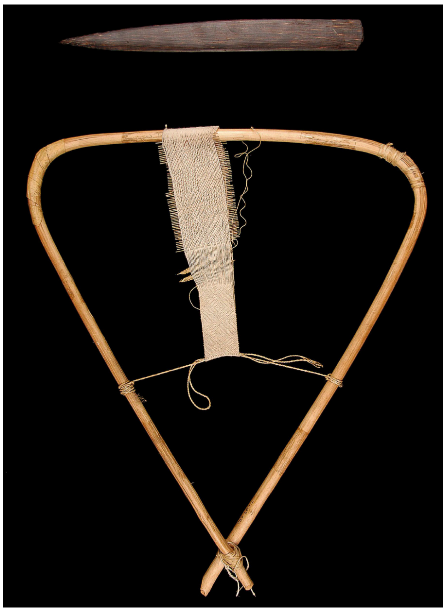


Image 3.4
Loom made of curved wooden stick
Image from Tools Magazine - Weaving volume 2 (2022, p. 203)

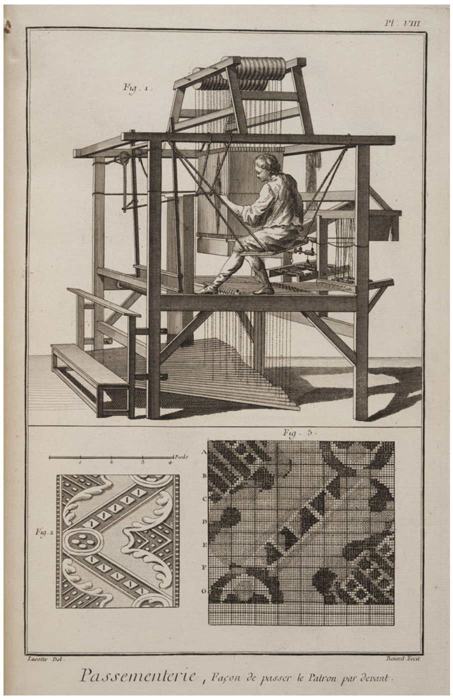


Image 3.5
Passementeries, façon de passer le patron par devant, plate from L'Encyclopédie, Diderot, 1762-1772
Image from MIT libraries exhibits

3.1.4.1 Punched card system

Joseph Marie Jacquard (1752-1834), a Frenchman from Lyon, didn't exactly invent the Jacquard mechanism. The system of perforated cards was first introduced by Bouchon (1725) and later refined by Vaucanson in 1745 whose cylindrical device allowed the reading of perforated paper. The need for such an invention was in response to the intensification of the Indian silk trade which demanded faster cloth production (Broudy, 1979). Also known as the "Jacquard head" (Marcoux, 1982, quoted in Davis and Davis, 2015, p. 79) the device, that Jacquard fine-tuned, was first a box to be mounted on top of a treadle-loom which "employed a quadrangular cylinder that carried an endless chain of cards perforated according to the desired pattern" (Broudy, 1979, p. 134). A treadle-loom is one where a lever actioned by foot operates the lifting of shafts. Essentially, Jacquard looms' mechanism permits the control of singular warp ends, as opposed to dobby looms which operate on a shaft system. That is to say, a set amount of warp ends lift together when the shaft on which warp yarns are threaded lifts. Although Jacquard looms enable more complex and wider patterns throughout the cloth, because of the amount of shaft a dobby loom can operate (four to forty-eight), intricate textiles can be executed. Pre-graph paper and pre-digitalisation, punched cards encoded the cloth (image 3.6).

Image 3.6
Series of punched card for a Jacquard loom
Image, National Museum Scotland

Within one card, each hole indicated which warp end to lift and each row of holes determined one weft pick shuttling. Although they are the equivalent of today's lifting plans, they visually propose a different notation of weave structure construction — one in which the hole actuates the machine. It is noteworthy that empty space here refers to a warp/weft crossing pattern as opposed to an unconsidered void — an observation valid for potential further research. To date, the modern (digitised) Jacquard and dobby looms use the same system of coloured squares for a lifting plan, threading and weave plan.

3.1.4.2 Digital notation

The introduction of electronic programmable computers drove the development of mechanised looms towards the digital space. This forwarded weave structure notation from the physical to the virtual. Computer assisted looms are controlled by software (e.g. WeavePoint, Pointcarré or Fiberworks) that follow the graph paper rigid matrix (image 3.7). In effect, digital weave structure notation only differs in the squares' colour, which encompass mainly, but not only, red, green, black, white and blue. Other more advanced softwares (e.g. Weft, CLO 3D, SEDDI Textura) use 'tilling tools' to design uninterrupted repeated sequences. State-of-the-art software, such as NedGraphics or Scottweave, offer 3D visualisation of threads pattern of interlacement, real-life fabric simulation, and 360° view of the designed woven cloth to be (image 3.8). There, the fluid/rigid paradox of a material woven cloth isn't applicable. Textiles are able to move, fold, and curve in identical ways to their physical equivalents.

Other research-based groups such as the Virtual Research Group (Rhode Island School of Design, Rhode Island, USA) have developed a library of self-shaping textiles, including, among others, visualisations of 'boundary distorsion', 'crumpling' or 'puckering' (image 3.9). Yet such a visualisation is generated on a triaxial grid. One could suggest that the potentials of this representation have yet to be explored sufficiently. For instance, in the 'puckering' sample, the grid is, at certain curving points, opening — hence breaking its assumed continuity. What could this uncover in regards to visualisation in the digital sphere that, today, requires x; y; z coordinates to be shaped? While such experimentations and cutting-edge weaving software is pushing the boundaries of textile visualisation in the virtual sphere, all continue to solely focus on a visualisation driven by horizontals and verticals and hence, a weave structure notation motivated by warp ends and weft picks.

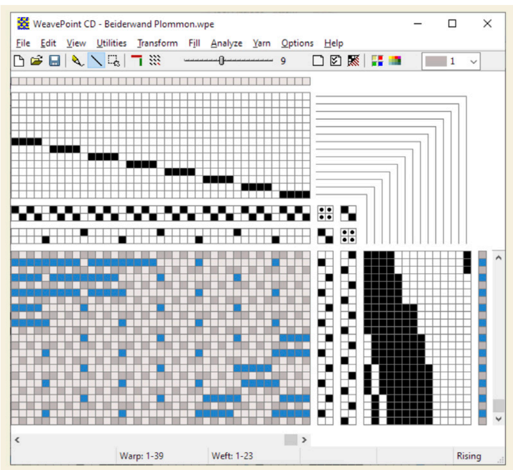


Image 3.7
Lifting, threading and weave plan
Image from WeavePoint

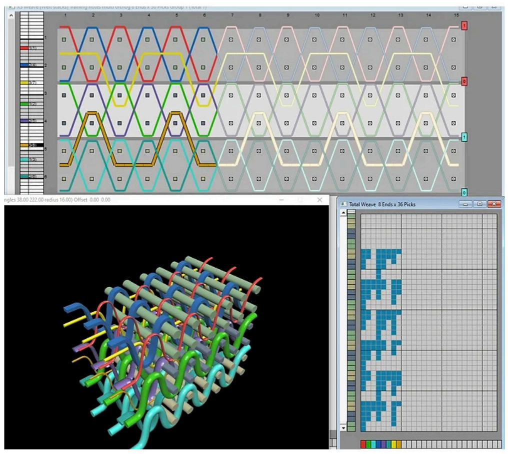


Image 3.8
3D visualisation of yarns' weaving pattern
Image from Scottweave

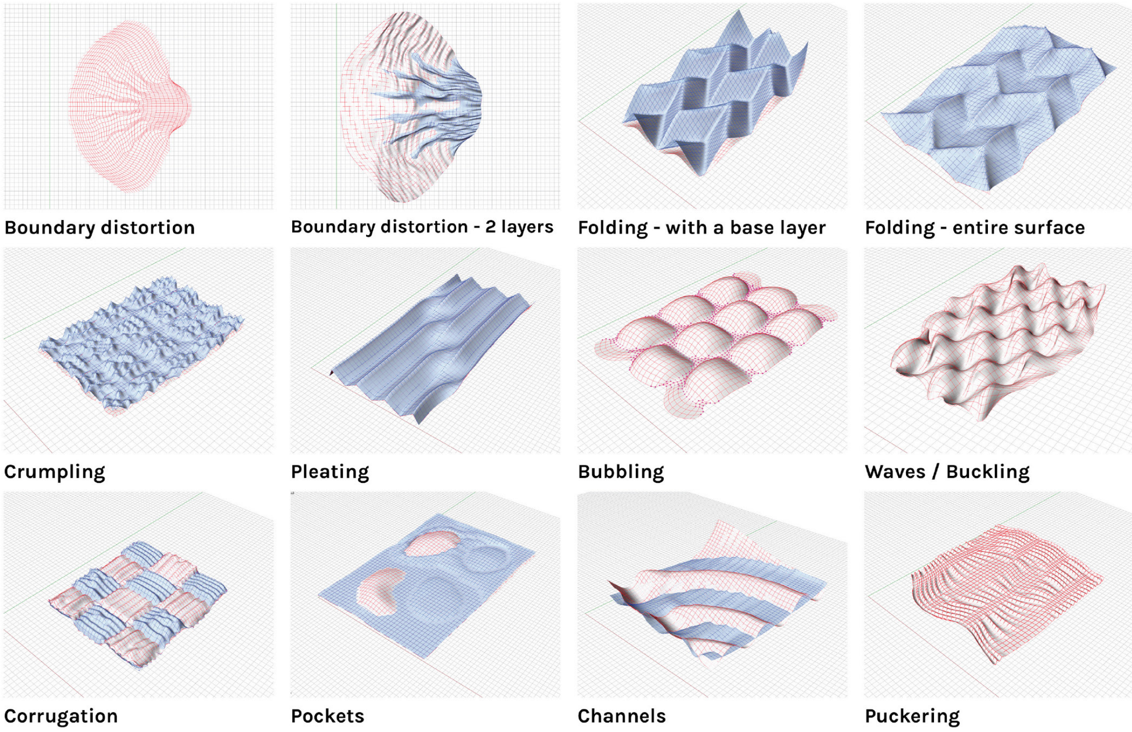


Image 3.9
Library of self-shaping textiles
Image from Virtual Research Group

Current loom technologies cannot comprehend any other form of notational system and still functions very well, which questions the need for an alternative perspective. Yet, such software requires little to no training in weaving to understand and design with them. They drastically simplify the design process of woven textiles for non-weavers. Indeed useful, as it speeds up making process, reduces sampling waste and doesn't require the expertise of trained weavers. However, it limits the scope of innovative outputs in the textile research landscape, meaning that research persists to focus on the engineering of new materials, i.e. for warp and weft, as opposed to their assembly process (Tandler, 2016). Thus as digital technology continues to play a role in the textile design research realm, not only is the intuitive and experiential knowledge of expert weavers overlooked, but industrial outlook persists. This is problematic in regards to possible new approaches that aim to rethink alternative ways of doing and not be restrained by industrial drivers, namely, reproduction, reproducibility, scalability, and mass-production. Because of its sole purpose for machine specification, the current weave structure notation limits the scope for alternative, non-linear techniques of production and thus application of novel economic models that foster localised production prospects, as opposed to industrialised outputs. Truly, once the signification of black and white squares configuration has been assimilated, operating the mechanised loom doesn't require extensive training into the craft. Yet, the lack of fundamental weaving knowledge, that is, the intuitive elements learnt through the experience of weaving, and the overreliance of the loom's specifications limits trained, trainee and inexperienced weavers to think beyond the confines of the grid's binary model. Likewise, designers, outside the textile field, are increasingly demanded to un- and re-think current rigid ways of doing to address urgent world issues, such as within the climate emergency. Therefore, this industrial-focused mode of making restricts creative practitioners to propose possible novel systems of thought and practice within and without the weaving research landscape.

3.1.5 'Technology'

In a post-industrialisation and post-digital age, the word 'technology' widely refers to a mechanised apparatus that requires little to no human input to function. Martin Heidegger's (1954) idea of technology is a 'logic of technē', in which a craft's "essence" isn't dependent on the mechanical. For him, 'technology' is in and of itself entirely separate to the machine. He affirms that "Technology is not equivalent to the essence of technology. […] the essence of technology is by no means anything technological" (p. 4). In Hedeggerian terms, a craft's essence is what the craft is. So dependent on machine specification and the grid notation, weavers, including myself, struggle to step away from automata, henceforth limiting their ability to think about and make woven cloth in non-linear ways for the purpose of creating novel designs.

Lehmann (2012) notes that historically, "labor structures" (p. 151) such as the aforementioned seventeenth-century guilds, encrypted knowledge and skills with regards to making processes and materials properties. Only members of these long-standing infrastructures could understand and apply traditional techniques. Criticising this traditional mode of passing down technical knowledge, hence including notating, he remarks that such a way of making isn't "conducive to innovation; only a deliberate departure allows for genuinely new knowledge to be generated" (p. 151). Lehmann thus discloses that departing from mechanically bound traditional modes of doing impart space for innovative ways of thinking and making. This idea is echoed in Walter Benjamin's (1936) understanding of tradition as a shifting concept.

Indeed, his allegory of craft — weaving and pottery — refers to pre-industrial ways of making (Leslie, 1998). He explains that prior to automation, the hand was the primary tool for image creation. Yet, the industrialisation of craft, including weaving, rapidly excluded the craftsman

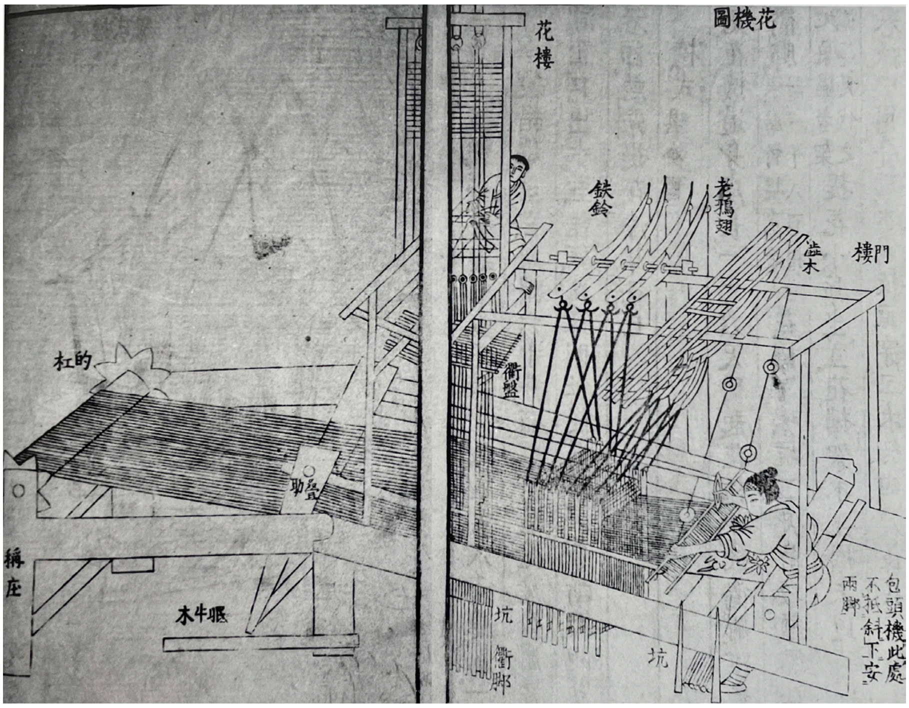


Image 3.10
A Chinese draw-loom
Plate from Albers (1965, p. 71)

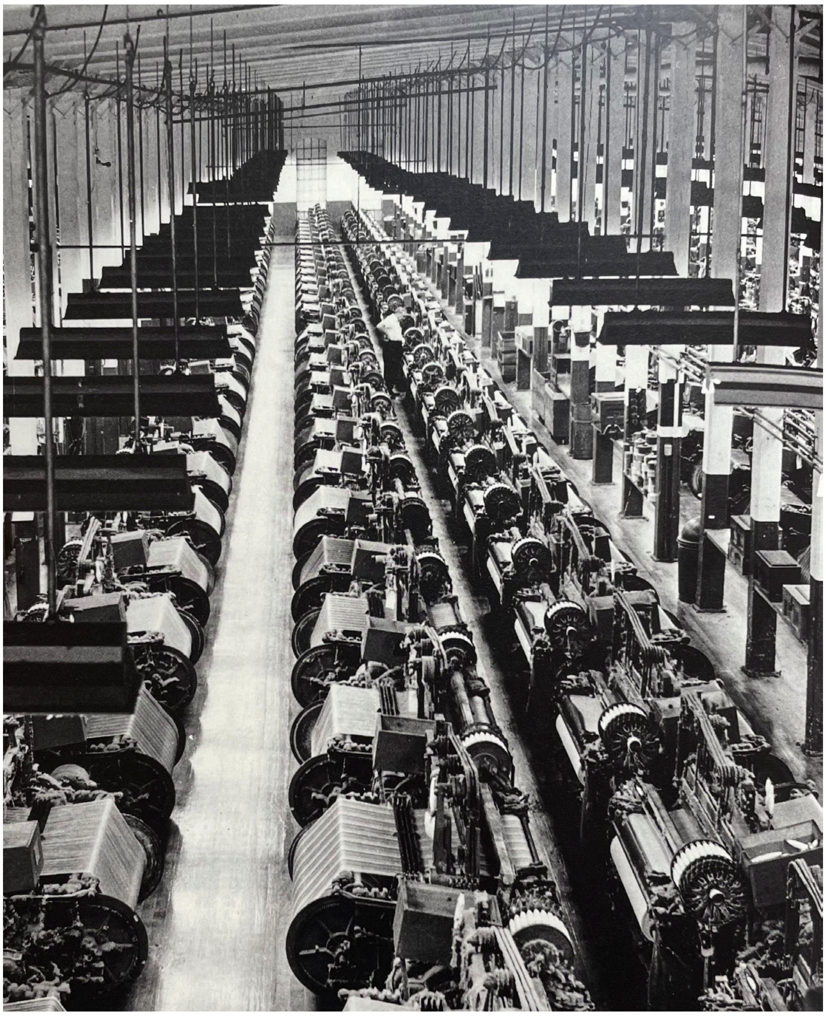


Image 3.11
A modern weaving room. One man is supervising the weaving of the looms shown here — in some cases as many as one hundred looms.
Photograph from Albers (1965, p. 71)

from their craft's tenet. In other words, industrialisation imposed deskilling in favour of modern mechanisms (Smith, 2016). The arrival of the Jacquard mechanism, for instance, completely dismantled the need for a draw-boy — the assistant weavers required to lift each warp ends every warp/weft crossing (image 3.10). As Gaskell (1836, quoted in Adamson, 2018, p. 60) notes, the development of mechanical production engendered a shift regarding the maker's role in cloth creation — becoming the "mere watcher of, and waiter upon, *automata*" (image 3.11). Reproduction and reproducibility are, for Walter Benjamin (1936), primal principles of post-industrialisation. In the sense that, by technological means, the earliest "work of art" (p. 11) is robbed from its original meaning, i.e. from the "truth" (Heidegger, 1954, p. 12) of its initial engineering characteristics. He writes,

> [...] the Greeks had only two processes for reproducing works of art technologically: casting and embossing. […] All the rest were unique and not capable of being reproduced by technological means (Benjamin, 1936, p. 11)

Henry Balfour (1893) corroborates this idea by reshaping the idea of evolution to "successive copying" (Song, 2014, p. 114). He attests that the copying of the original hand-made work of art always encounters variations whether or not intentional. Besides, accurate copying isn't realistic without the skilled hands of the maker, even with identical, mediocre or new mechanised tools.

In *The Problem with Craft*, T'ai Smith (2016) outlines David Pye's (1995) twofold identification of making, namely "workmanship of certainty" (p. 80) which refers to industrial processes and "workmanship of risk" (p. 80), pertaining to one-time, original fabrication. However, Pye maintains that whether produced by hand or by machine, the product is always simultaneously unchained (craft) and controlled (industry). Smith (2016) stresses how this radical logic notably promoted the outsider status craft has held throughout modernism. Rightly, she raises how such non-differentiation between hand-made and industry-made interrogates the "values regarding things and the labour involved in making them" (p. 80). This might be why, outside of the discipline's realm, unfettered attitudes — linked to intuitive and experiential skills — towards making woven cloth are discounted, leading to the difficulty for non-weavers to engage with the craft with originality.

The automation of weaving, thus led to the oversight of weaving's originally unmechanical identity. Walter Benjamin (1936) eloquently writes on the dynamic nature of tradition that actively shapes the ways in which the craftsman apprehend their craft. In other words, tradition's "extraordinarily changeable" nature and the "uniqueness" (p. 10) of the original craftwork are indistinguishable, which enable makers to alter and further the discipline. Changing the craft's engineering principles isn't the aim of this thesis. Instead, as mentioned in chapter 01, it focuses on exploring whether another perspective on visualising weave structure can shed light onto how other professionals — both weavers and non-weavers — understand woven cloth and engage with its construction principles. This approach is developed through the analysis of the empty spaces in-between and within yarns, in order to illustrate their potential role and value as part and a part of a complex holistic system — one in which all components, i.e. yarns and holes, hold equal status and importance. Thus investigating weaving's notational system requires understanding the ways in which woven textiles are assembled.

3.2 Assembly system

Weave structures are complex systems of interlaced elements. Yet, the way in which such systems are constructed and therefore notated is solely driven by physical textile components (e.g. yarns, sensors) which are undeniably inherent constituents of woven textiles. Accordingly, raw materials with which cloth is woven are as much a deciding feature as the weave structure (Albers, 1965; Berger, 1930). Thus for weavers, including myself, making cloth requires thinking through threads.

Exploring fibre's role in shaping woven textiles matrix, Hengge and Krauthausen (2023) commemorate pioneer weaver Anni Albers' words by writing,

> We do not regard a thread as an everyday object or a passive
> material — no, a thread is an active occurrence that emerges
> from the everyday to become an 'event'. A thread attracts attention. (p. 22)

Their essay, like countless textiles theorists' accounts, allude to the Bauhaus weaver's famous phrase "the event of a thread" (Albers, 1965, p. xi). For the maker, weaving is ruled by warp and weft's itinerant journey, whose pattern of interlacement brings woven cloth to life. Weaving is indeed commonly described as a systematic, ordered and hierarchical spatial aggregate of elements. The antithesis weaving embodies, i.e. an orderly, rigid network, still fluid and able to fold itself into various shapes (Barnett, 1999; Pajaczkowska, 2005), does not coincide with modern weave structure notation. That is, the rigid matrix of uniform squares is supposed to encode a flexible and soft cloth, able to fold itself into three-dimensional shapes, but fails to do so. While the paradox within weaving is noted and accepted by many, if not all textile philosophers, no account has questioned whether another element, aside from threads, might be responsible for this incongruity.

3.2.1 'Weave' and 'weave structure'

Weave structures and the technology of weaving are evidently inseparable because 'to weave' gives rise to a 'weave structure', i.e. a woven matrix. Nonetheless, for many, a 'weave' and a 'weave structure' are perceived to be identical — not as distinct types of constructs: a technology and a topology, respectively. This might be why the fluidity and unpredictability of woven cloth is now confined to graph paper notation.

Proceeding from Albers' (1965) writings on weaving's fundamental construct, art historian Charlotte Healy (2019) writes of 'weave' and 'weave structure' as terms alike in meaning. The word 'weave' is in fact simultaneously a noun and a verb. The former etymologically means 'something woven', implying motion. The latter stems from the Proto-Indo-European *(h)uebh* (v.), 'to move quickly'. 'Weave' therefore refers to both an activity and a woven 'thing', i.e. the product of this activity — forgiving the difficulty to distinguish 'weave' from 'weave structure'.

Smith (2014, quoted in Healy, 2022, p. 108) remarks that, in the woven work of female weavers of the Bauhaus, weave structures were always "in the process of being woven". 'Weave' and 'weave structure' clearly share the idea of movement. Yet one can wonder whether the terms share the same meaning. Could they be "a subtle tautology that contradicts the differentiation between weaving as process and weaving as structure?" (Fourquier, 2024, p. 5). As stated earlier, a drafting plan indicates how warp ends are mounted on the loom which digitally employs the same black/white square system as the modern weave structure notation. This anchors further the confusion between 'to weave' — assembly process — and a 'weave structure' — assembly system —. Hence within weaving engineering methodology and weave structure notation, the overriding status of warp and weft continues to be paramount.

3.2.2 Technological construct and raw material

A *weave structure* notation is commonly referred to as a *weave* plan. Otti Berger (1930), a prominent weaver of the Bauhaus, proposes that the 'Struktur' of woven textile is a pivotal agent of designing cloth. She borrows the German word from Paul Klee's (1921-1931) lectures on pictorial configuration, which states that 'Struktur' refers to the innate or stated structure of things, i.e. the material properties. He clearly delineates 'Struktur' from 'Faktur', i.e. the distinct and dynamic ways in which a surface plane is created (Healy, 2019). In regards to weaving, Klee's theory articulates the obvious difference between 'weave' as a topology ('Struktur') and 'weave' as a technology ('Faktur'). Raum (2019) analyses Berger's writing on the structural potential and need for various structures (Hemmings, 2023). To borrow Berger's (1930, quoted in Raum, 2019, p. 111) words, a weave is "the way of enmeshing threads" and "different weaves", confers to cloth's tensility, tension and texture — referring to material properties and weave structure together. Consequently and thus far, it articulates how the process of making woven cloth demands consonance between structure and raw material.

Some attest that the study of weave structure is merely an analysis of a highly complex geometrical system, and that its assembly parameters are a translation into mathematical formulas. Such a blueprint would be representative of the structure's engineering properties (Nikolić, 1985, cited in Lecović, 2022). While this might be true because algebra and weaving methodology are intricately intertwined, this reductionist reasoning only takes into consideration the constitutive mechanics of woven textiles. In effect, it disregards their unique fluid and folding nature, that is, their behaviour in various conditions. Woven textiles' performance is thus dependent on their structure and the materials of which they are composed.

3.3 Material systems

Textiles, including woven ones, are composed of various material elements, each of which are assembled within a larger structural system. In other words, textiles are "material systems" (Tandler, 2016, p. 36). Today, the ways in which woven textiles' are assembled is known, accepted and unquestioned. As stated in section 3.1.4, the loom's mechanisation succeeded the rapid development of yarn spinning techniques and thus machinery, in order to respond to the intensification of the Indian silk trade throughout the eighteenth-century (Broudy, 1979, p. 134).

The 1990s saw rapid growth in material advancement, also known as 'smart'. The notion of 'smart' needs addressing because it contributes to the ways in which research into textile continues to solely focus on the development of tangible materials — in turn reinforcing their precedence in weaving construction methodology.

3.3.1 'Smart' material systems

Khipu (quipu), a traditional Inca recording instrument made of knotted strands of yarn, could be considered the first 'smart' material system. The Andean textile ornament was used to communicate numerical data between people. While deciphering their meaning is still an issue today as they "do not fit into any known numeric coding system" (Rohrhuber and Griffiths, 2017, p. 144), the apparatus' systemic 'Faktur' or surface treatment displays its functionality. This means that unlike today's 'smart' material systems, quipus' 'smartness' is not dependent on the material, i.e. cotton cord, with which it is made but on the ways in which it is put together (image 3.12).

Image 3.12
Khipu (quipu) fragment with subsidiary cords, Inka, 1400–1570, cotton and indigo dye, from Quave (no date)
Image from Dallas Museum of Art

The turn of the century saw numerous publications associating structure with the term 'smart', in regards to the study of materials' scaffold and their ensuing functions. Such research describes these materials as smart because of the ways in which they behave. Accounts explain that smart materials can sense and react to their environment and adapt their response accordingly (Wadhawan, 2007; Tao, 2001; Furuya, 2000, cited in Tandler, 2016); and that their complexity grades their level of 'smartness'. Here, materials' 'smart' behaviour relates to the material itself but does not take into account its relation to other components, nor its localisation within a structured 'material system'.

Tandler (2016) explains that the term 'smart' should refer to the fact that a textile's smartness is dependent on the materials of which it is composed, their intended capabilities and performance as a part of that textile — not the fabric itself. Her account, which has remained the only one to date, challenged the misuse of 'smart' by explaining that textile components' structure, i.e. materials (e.g. sensors, alloys, graphene, fibres) defines a fabric's "intelligent behavior" (p. 38), i.e. performance, functions, applications and aesthetics. As such, 'smart' should refer to the functionalities of a network (textile construct) of systems (materials). That is to say, the ways in which each textile component is assembled as a part of a structured whole. Following Tandler's logic, it is therefore the relationship of the textile components to the whole structure that enables the system's performance. In other words, 'smart' textiles are not a mere assemblage of isolated smart parts. Yet until now, yarns, that is, their material composition and structure, have been the sole target of innovation in constructed textiles.

3.3.2 The primacy of threads

In 1946, Anni Albers stressed that new developments in woven textiles had shown little concern for weaving and its technique, i.e. the aforementioned 'Structur'. Fifty years later, Tandler (2016) argues that there has not been any exploration in weave structures that could make a textile intelligent. To date, research still focuses on the geometries of components, not their assembly. In fact, material scientists Loke et al. (2020, p. 786) affirm that "the key to transforming fabrics is through a new class of highly technological, rapidly evolving fiber materials that look like traditional fibers but behave more like computer chips". Likewise, Lee et al. (2023, p. 1) present the first ever "truly form-factor-free" woven textile. The fabric's matrix is composed of four different kinds of 'smart' fibre-devices each performing specifically for the woven system to function intelligently. While such groundbreaking studies propose new developments in the field of textiles, they forget about weave structure and blindly focus on the structure of tangible material elements.

In woven textiles, recent innovations claim to have developed new structural construction. For instance, with *Adaptex*, Sauer, Waldhör and Schneider (2017-2022) develop 'textile systems' made of Shape Memory Alloys (SMA) able to shape-change their structures under environmental shifts — hence altering the woven material's matrix (image 3.13). Equally, *Hydroweave* (Eichler and Neyenhuys, 2020) focuses on hygroscopic motion's principles of materials — size- and shape-change of natural cellulosic fibres — which affects the woven textile's shape when exposed to moisture (image 3.14). However, neither project was driven by weave architectures development, but by the known 'smartness' of the materials used. As such, if the woven membranes weren't made with those specific 'smart' materials — SMAs and cellulose-based fibre respectively — the intended action wouldn't work, limiting its adaptive functions in various contexts. In the field of material science, so-called "programmable" or "architected" (Sauer and Stoll, 2023, p. 11) materials have properties that are dependent on their constructed inner structure. Although innovative materials keep being fashioned in order for textiles to be 'smarter', their structural assembly is not taken into account. As a result, research continues to disregard the potentials of other kinds of materials, that is to say, empty space. The inspiration for this research arose from observing the structure of woven textiles, and realising that without holes in-between warp and weft woven cloth would be a mere aggregate of loose verticals and horizontals. This is why research proposes to see the hole as a component of a whole woven matrix — identifying it as a tool to study weave structure visualisation from an alternative perspective (chapter 04).

Image 3.13
Hydroweave, from Eichler and Neyenhuys (2020)
Image from Matters of Activity

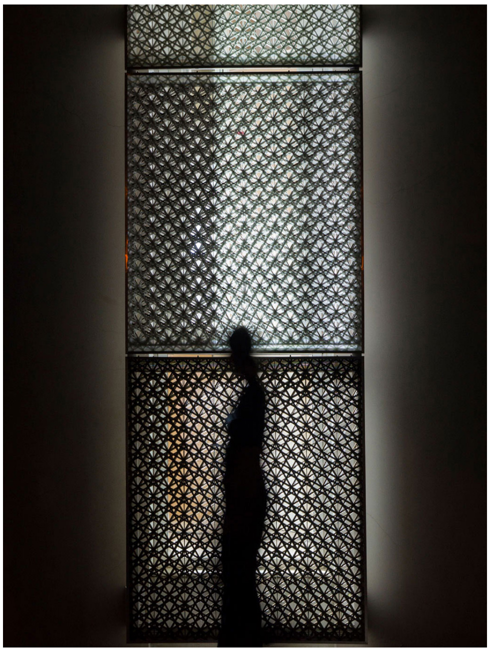


Image 3.14
Adaptex
Image from Sauer, Waldhör and Schneider (2017-2022)

3.3.3 Hole textiles

Some textile constructs can be characterised as 'hole textiles'. That is to say, textiles that are made up of well-defined holes while maintaining a great degree of stability and durability. Such constructs include different techniques such as twisting, braiding, interlinking or knotting. Among these techniques are bobbin lace, macramé, knitted lace, or sprang (images 3.15; 3.16; 3.17; 3.18). Although they vary in construction methodology, they lead to the creation of evident gaps in-between threads.

As with weaving, the first structural notations of these primitive textile constructs are unknown. Yet accounts have successfully transcribed them into diagrams, adequate to be used as design tools for reproduction. In comparison to weave structures, their notational systems are not confined to the checkerboard. Some visually reflect the ways in which yarns inter- lace, lock, twine (e.g. bobbin lace, knitted lace) while others (e.g. sprang, macramé, knotted structures) employ other types of symbols. For instance, Nimkulrat, Matthews and Nurmi (2017) paired mathematical tiling — using Wang Notation and Rotated Wang — with knot diagram to create a new tile notation for knot patterns. Here one can observe a geometric square-like grid, within which areas are filled with white or black in a specific ordered manner. These coloured surfaces indicate the strands, knot type and placement that form the complete knotted textile structure (figure 3.7). Likewise, bobbin lace notation pictures twisting and twirling lines on and around themselves (Scott and Cook, 1982). In essence, these diagrams are drawn images of the bobbin lace to be. Perforated working diagrams, or 'prickings', in which small holes identify pins position (figure 3.8), help the maker draw out their designs (Hardeman, 1982). In *Textiles of Ancient Peru and their Techniques*, D'Harcourt (1962) visualises plaited fabrics through small circles, at times fully filled, at others incorporating a cross. Arranged in a circular formation, they symbolise the "successive positions of the strands" (p. 93) while arrows link the small circles, hence encoding the yarns' pattern of assembly (figure 3.9).

It is noteworthy that these structural diagrams are very different from those of weaving, in that they do not use coloured squares to visualise the thread's pattern of interlacement. Yet even if the gaps in-between threads are evidently essential to create such textiles, as in weaving, their notation does not visualise these voids. In other words, the notations of other 'hole textiles' also fail to acknowledge negative space's potential value and instead favours picturing the networks of threads with lines alone.

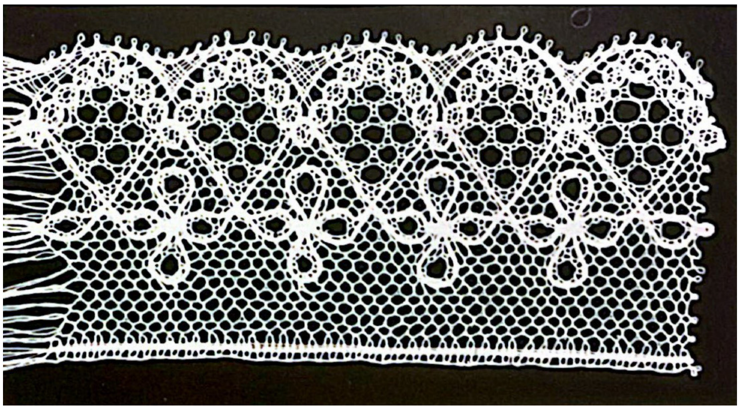


Image 3.15
Bobbin lace of a fourleafed clover pattern from Scott and Cook (1982, p. 63)

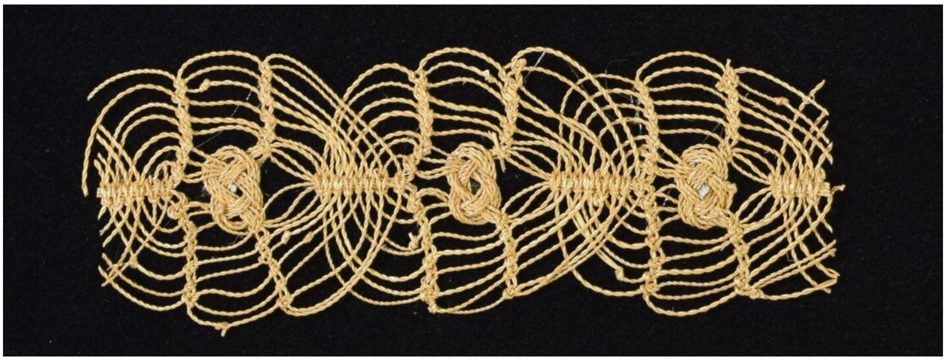


Image 3.16
Straw braid made in knitting and macramé techniques, 1860-1870 (made), Jacob Isler & Co., Wohlen
Image from Victoria and Albert Museum

Image 3.17
Shawl made in knitted lace technique, Amy Johnston, 1935, Baltasound, Unst, Shetland islands
Image from Victoria and Albert Museum

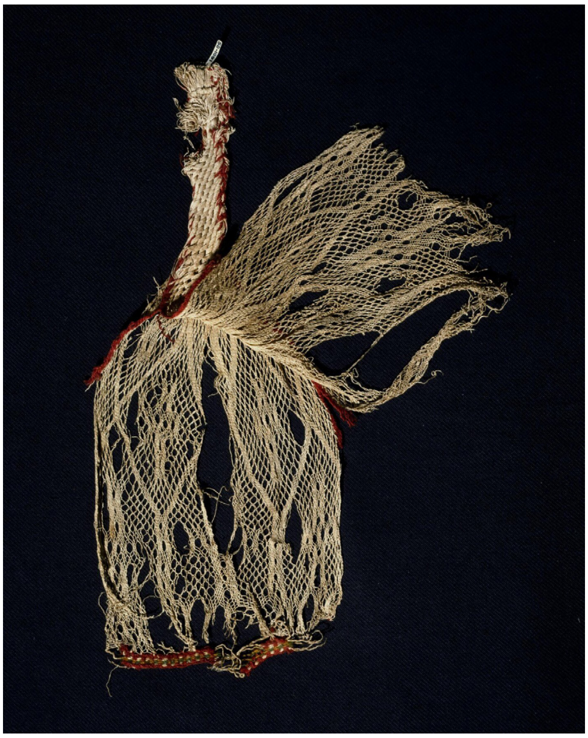


Image 3.18
Linen cap made in sprang technique, 330-540, Egypt
Image from Victoria and Albert Museum

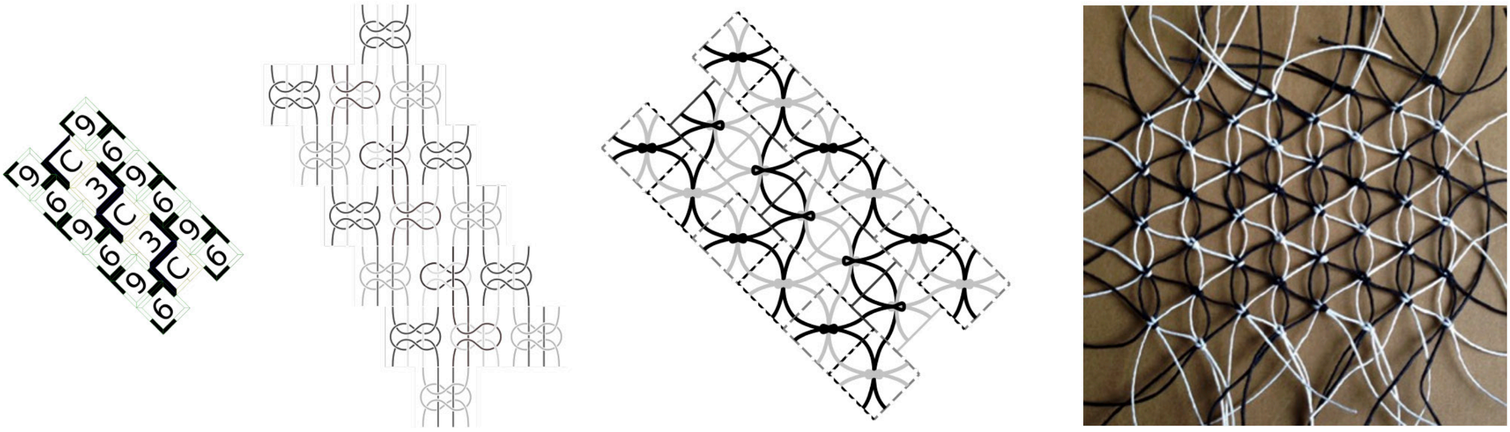


Figure 3.7
Knot diagram for a new tile notation
from Nimkulrat, Matthews and Nurmi (2017)

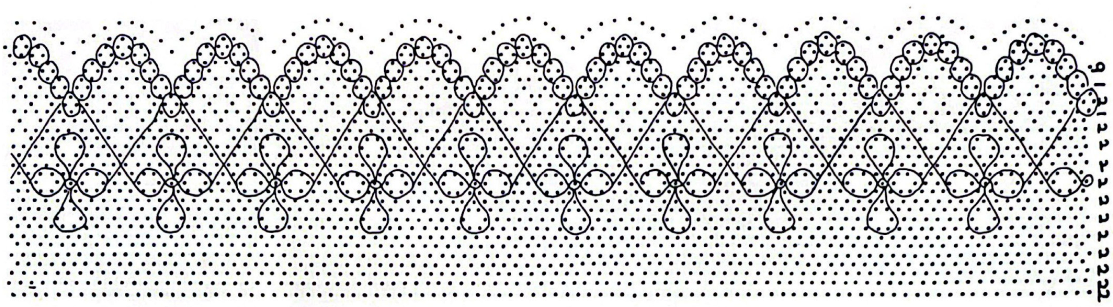


Figure 3.8
Bobbin lace pricking for fourleafed clover pattern
from Scott and Cook (1982, p. 63)

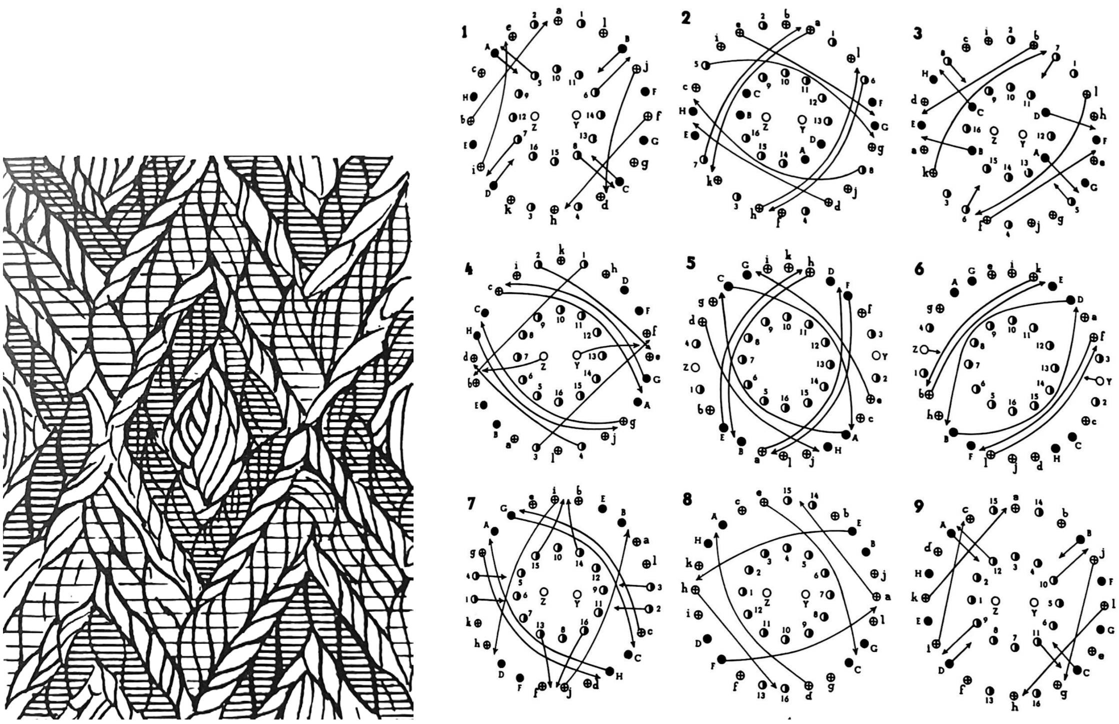


Figure 3.9
Plaiting diagrams with thirty-eight strands, 1-9 successive positions of the strands and the corresponding textile, from d'Harcourt (1962, p. 93)

The technique of sprang, meanwhile, differentiates itself from other 'hole textiles', including gauze (leno) weaving in that the primary method for making sprang cloth "is the controlled production of holes in the normal interlinked mesh" (Collingwood, 1974, p. 132). In other words 'hole design' enables the planning of the forthcoming sprang fabric. While sprang is designed through hole patterning, its notation today remains confined to the grid: white squares signify two warp threads twinning and a square filled with line indicates a non-crossing of yarns, i.e. a hole (figure 3.10). Thus in this textile method, holes are an inherent element of a textile structure, if not one that drives its making.

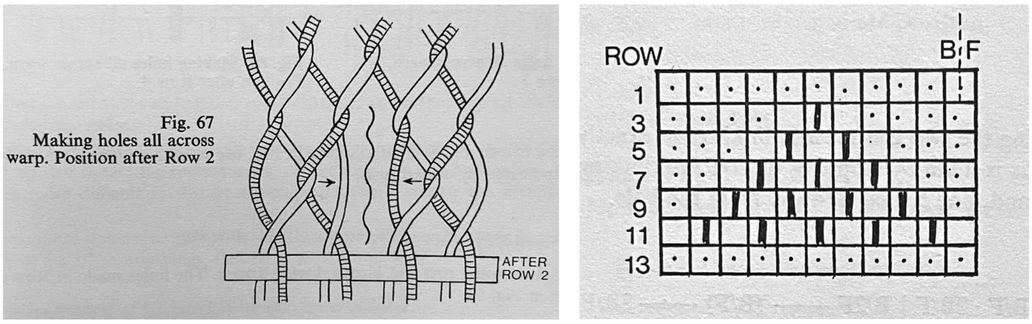


Figure 3.10
Hole design diagram and sprang notation
from Collingwood (1974)

3.3.4 Embedded data

Reflecting back on quipu's enigma, Knill (2018) writes that "It is not so much the topology of quipu which is of interest for researchers but the information content which is encoded topologically" (p. 2). Thus, it is neither textile material nor its structural makeup that poses questions. Rather, quipu's conundrum is concerned with the unseen data embedded in the material system. What Knill pertains to relates to the numerical encrypted data within the knotted textile construct. Nevertheless, his reflection can be applied to woven textiles and the meaning that they carry. As textiles live through time, remains of their construction not only indicates the assembly techniques of ancient civilisations but also recount "a culture's social and religious beliefs" as well as "a society's natural, economic and social changes" (Kruger, 2002, p. 12). The mechanisation of the loom and its effects on society's modes of existence and operation are reflected in the woven textiles that were born from it. Decreasing time of production, drastically lowering workforce and fostering uniformity and accuracy of cloth are prime examples of economic, societal, cultural and social transformations. Indeed, scalability, mass-consumption, linear approaches and scientific techniques of creation became drivers of Industrialisation. Thus, as stated in section 3.1.2, early weaver's tacit ways of knowing and making were forgotten. Yet much can be learnt from pre-industrial weaving knowledge, which focuses on the craft's method as opposed to the manufacturing tools associated with it (Albers, 1965). As tacit knowing is at the heart of the approach this thesis takes towards developing another weave structure visualisation, one must explore what intuitive knowledge is and how it can serve alternative ways of thinking and doing for weaving. Research turns towards human intelligence in order to understand better the role of intuition and experience in more holistic modes of making that aim to step away from the mechanical. Writing on Johnson's (2017) words, Nimkulrat (2025) explains that

> cognition is situated in a dynamic organism-environment relationship that is constantly activated according to the needs, interests, and values of these organisms, including humans (p. 142).

Consequently, to thoroughly understand what a holistic approach to weave structure visualisation entails, the thesis must examine the processes by which humankind apprehends the world and here, making.

3.4. Intelligent system

'Intelligence' typically refers to cognitive intelligence, that is, the faculty to logically learn and understand things. However, no consensus has been reached as to its scientific, philosophical and psychological meaning (Spearman, 1922; Pfeifer and Scheier, 1999). This lack of scholarly unity is reflected in the latent difference between the concepts of 'knowledge', 'intelligence' and 'understanding'.

A differentiation between knowledge and intelligence is noteworthy. As Ceci (1996) explains, "it is possible to be knowledgeable without being intelligent" (p. 16). He in turn identifies knowledge — a skill or information generated from previous knowledge — and intelligence — the ability to use that skill in an effective manner — as divergent concepts. As an ability, intelligence is also portrayed as being partly inborn rather than as a quality that one can gain.

3.4.1 'Non-intellective' factors

Gardner (1983) describes that, biologically, intelligence is dependent on the connectivity between several sensory systems. Cognition might therefore be a component of a system determining one's intelligence. The 20th century brought new perspectives on individuals' "non-intellective" facets (Wechsler, 1934 quoted in Grewal, 2005, p. 330) — that is, emotions and feelings and their contribution to general intelligence. In 1994, Damasio boldly denounced 'Descartes' error' — the dualist concept of the separation of mind and brain, i.e. body. He identifies this obstruction as an oversight on the role of the corporeal "nonthinking body, that which has extensions and mechanical parts" (p. 248) in the expression of emotions.

Gazzaniga (1972, cited in LeDoux, 1998) distinguishes left and right brain, respectively responsible for rational thinking — linguistics, mathematics, analysis — and emotional thinking — creativity, feelings —. His and LeDoux's research showed that left and right hemispheres would stop communicating when surgically separated. This supported the notion of an 'emotional brain', and demonstrated its interdependency and synergy with the cognitive. Later, Rolls (2007) conceptualises that emotion processing is independent from cognition — presenting 'non-intellective' facets, or skills, as components of an intelligent system that interact with other systems of intelligence.

Experience and intuition notably exceed cognitive capabilities and might have to do with emotionally intelligent ways of doing things. Emotional intelligence has been widely researched in the realm of psychology, sociology, anthropology and science since its introduction by Howard Gardner (1975). His theory of multiple intelligences frames emotional intelligence as being part of a system of intelligences which connectivity enables the whole system to perform. For Gardner, inter- and intrapersonal intelligences are part of what defines emotional intelligence. They respectively refer to the ability to appraise other's emotions and apply one's own emotional skills in different contexts. The former has to do with intuitive ways of understanding things while the latter pertains to learnt techniques of doing. Social psychologist Salovey and Mayer (1990, p. 189) propelled emotional intelligence to the forefront of the debate on the concept of intelligence and defined it as "the ability to monitor one's own and others feelings and emotions to discriminate among them and to use this information to guide one's own thinking and action". To this day, accounts affirm the validity of emotional intelligence as an intelligence in its own right (O'Connor, 2019; Bar-On, 2006; Ashkanasy & Daus, 2005;

Grewal, 2005; Feldman Barrett, 2002; George, 2000; Caruso, 1998; Goleman, 1998; Mayer & Salovey, 1995; Gardner, 1993; Salovey & Mayer, 1993), while others contest its cogency and value (Locke, 2005; Zeidner et al., 2001; Davies, Stankov & Roberts, 1998). Nimkulrat (2025) explains that during practice the maker is aware and responsive to the environment in which they create, thus able to sense "the nuances of their making process and eventually responding unreflectively yet effectively to the new situations" (p. 142). Although she speaks of skill assimilation, this reflection is attuned to emotional intelligence, that is, one's capacity to discern and react in situ permits adapting to whatever comes through making. As a result, emotionally intelligent attitudes towards the research suggest more intuitive and intelligent modes of thinking and making.

3.4.2 'Knowledge', 'understanding', 'tacit knowing'

For pathbreaker Micheal Polanyi (1966) 'understanding' is rooted in the ability of individuals to learn things from experience (Gulick, 2017). 'Understanding' is ineffable, elusive, intuitive, experiential. It emerges from tacit processes that "nurtures significant explicit thought and action" (p. 85). The aforementioned 'knowledge' is therefore more explicit, reflects objectivity and embodies Descartes' rigid (Cartesian) definition of knowledge (ibid.) that had a pervasive influence throughout industrial advancements. Polanyi (1966) also interchanges 'understanding' with 'tacit knowing' and proposes that knowledge is a process or an activity as opposed to a static form of knowing. Yet, contrary to Gulick's (2017) argument, he doesn't reject explicit knowledge, nor does he prioritise tacit knowing over it. In fact, while distinguishing 'knowing what' — an intellectual form of knowing — from 'knowing how' — a practical one — he presents this form of doing (tacit) as an essential element to explicit knowledge (cognitive). Additionally, Gulick proposes that tacit knowing incorporates "interpersonal" (p. 85) and psychological parameters with experience, a definition that mirrors the one of emotional intelligence, on which he fails to remark. This validates the bridge between emotionally intelligent attitudes or tacit ways of doing with cognitive ones. Furthering Polanyi's research, Wagner and Sternberg (1985) explain that it is "not openly expressed or stated" in contrast to explicit knowledge that is "directly taught in classrooms" (ibid., quoted in Cianciolo et al., 2006, p. 615). Thus, the acts of "'making sense' of things" (Gottfredson, 1997, quoted in Burkart, 2017, p. 2) reflect a more intuitive and insightful way of knowing and understanding. Conversely, David Pye (1964, cited in Ingold, 2011) calls 'know-how' which, he suggests, is equivalent to technology, the ability to imagine form prior to realisation. For this to be possible, skills, i.e. one's capacity to do things agilely, and the ways in which to implement such skills is needed. However, the author questions whether there can ever be know-how without knowledge. While Pye's reflection relates to identifying a definition for technology, his argument corroborates that, in making, explicit and implicit forms of knowing are intertwined.

Dormer (1994, cited in Igoe, 2010) qualifies as 'taciturn', i.e. 'quiet', the maker unable to articulate their experience of making. That is not to say a lack of intelligence. Rather, as Albers (1944) defends it, one that manifests itself in other hidden, more intuitive ways. Here tacit ways of studying weave structure visualisation enables the maker-researcher to follow their intuition, in order to break away from a purely technical lens. Philpott (2011) writes that as for textile practices, tacit knowledge isn't a static mode of knowing. It is the sensual interaction, i.e. sight, touch, smell, with materials that enables the practitioner to assimilate new ways of 'understanding' their craft — in the Polanyian sense of the word. As Lehmann (2012) writes,

> [...] intuition assumes a fundamental role within knowledge formation by apprehending definitions that cannot be scientifically (logically) demonstrated (p. 152).

Because the activity of weaving is a combination of experiential knowledge with technical expertise, fuelled with imagination and creativity, it is this intuitive approach that makes prominent hitherto unacknowledged elements. In the context of weave structure notation, the tacit ways of knowing and doing therefore enables the study's alternative approach to understanding woven textiles as a pliable network of systems — one in which all components are intrinsic to its existence (chapter 04).

For many, 'to craft' involves a certain level of internal experiential knowledge (Nimkulrat, 2012) which is carried through the maker's hands. In the course of making, "the hand becomes intellectual, enabling the simultaneous creation and analysis of work" (Philpott, 2011, p. 121). As such, hands' experience of doing can often convey more than what the maker has intellectualised (Leader, 2016). This makes sense in regards to ancient weaving practices and the absence of a notational system. Indeed, as stated in section 3.1.1, weaving knowledge was in all probability passed on through observing, listening, doing and repeating. As such, for both the weaver and their apprentice, knowledge embodied in the hand was and still is, crucial to the making of woven cloth.

3.4.3 'Understanding' through tools

As Albers (1965, p. 4) puts it, "Any weaving, even the most elaborate, can be done, given time, with a minimum of equipment". Writing on hands' agency, Leader (2016, p. 6) states that Greek philosophers Anaxagoras (circa. 500-428 BCE) believed that "humans are intelligent because they have hands" while Aristotle (circa. 384-322 BCE) deemed that "they have hands because they are intelligent". Although contradictory, these opposing thoughts illustrate that, in the context of weaving, implicit and explicit knowledge are part of a wider system of information processing, i.e. intelligence. Polanyi (1966) writes that learning and understanding things through tools relates to humans' ability to use them as a prolongation or an inclusive part of the body. He asserts that "Our body is the ultimate instrument of all our external knowledge, whether intellectual or practical" (p. 15). This suggests that Anaxagoras and Aristotle's ideas correlate, in that hands' tacit and learnt ways of doing and reasoning are intrinsic to humankind's ability to create, make, function and understand reality. Additionally, at the core of Polanyi's (1966) philosophy is the interaction between ways of knowing, which relationship enables the whole system to perform. Precisely, a holistic way of thinking that imparts individuals — here the maker-researcher — the ability to employ their acquired knowledge and tacit ways of knowing, in order to adopt new perspectives on their craft.

This translates practically into the attitude taken here to study weave structure visualisation. Indeed research approaches visualisation from an understanding of notating weave structure as a holistic system — one in which all components are identified. What does all components mean? Polanyi's notion of tacit knowing, in simple terms, refers to hidden, ineffable, unseen data. To date, what has remained unseen in weave structures, and by extension their notation, is the empty space in between warp and weft, which this research proposes to see as a 'material' component of a woven textile's structure. This argument is presented in the succeeding chapter (04).

This chapter began by stating that looking into ancestral weaving knowledge can be a revelatory way of exploring the future. Ingold (2011) writes profoundly,

> If technology is all toolmaking and tool-using, guided only

> during the modern era by scientific knowledge, [...] what kind of knowledge could have informed the making activities of pre-modern societies (p. 297).

Following the aforementioned notion of the tool as an extension of the human body, Ingold's question initiates the idea that the empty space in-between warp and weft might hold insightful weaving knowledge and therefore could be seen as a pre-industrial tool to investigate an alternative way of notating weave structure.

04.

a conceptual look on negative space

Tool & lens

04. Tool and lens — a conceptual look on negative space

While the study is led by a practical examination of negative space, the research requires an understanding of the concept theoretically in textiles, architecture and geometry, in order to understand how other disciplines approach empty space and understand non-linear shapes. All the more because the thesis aims to evidence the need for another perspective on weave structure visualisation. Furthermore, because empty space isn't the primary focus of this study, the thesis must identify and explain how it is broached and why it is pertinent.

Research into negative space in textiles has mainly been confined to aesthetic properties or mechanical functions. In creative practices, the term 'negative' is often employed to characterise a physical surface surrounding a pattern, allowing such patterns to take shape. 'Negative' only makes sense in relation to its opposite, namely 'positive'. For instance, the Japanese term 'Notan' (image 4.1), signifying light-dark harmony, indicates 'positive' and 'negative' in terms of colour value — a technique widely used in quilting and print-making (Milne, 2012). In this thesis however, the term 'negative' relates to the non-solid areas in-between threads.

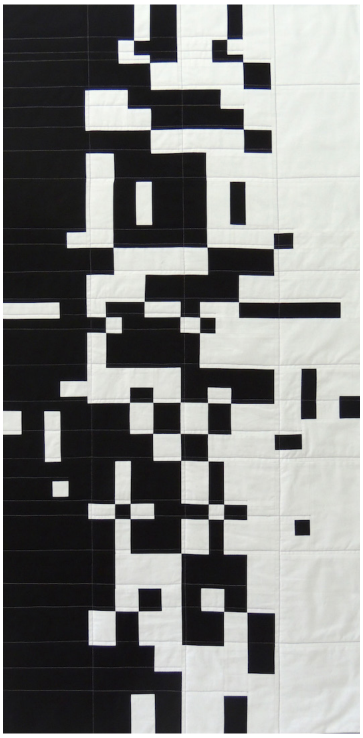


Image 4.1:
Quilt fabric using the technique of Notan
Image from Springleaf Studios (2019)

The following chapter explores negative space through a conceptual lens to understand how research might use it as a practical tool to visually study weave structure (chapters 05 and 06). The idea of negative space as tool and lens is thoroughly explained at the end of this chapter. But before doing so, the chapter interweaves conceptual reflections drawn from textile philosophy, specifically the link between textile and text because woven textiles are thought to be the earliest mode of communication (Kruger, 2022), that is to say, knowledge transfer and cultural stories permeation (chapter 03). New performative materialism conveys a semantic examination of nothingness and its implication within the distinction between material and materiality; henceforth enabling approaching negative space as an inherent component of weave structure. Architecture and fractal geometry respectively enable a reflection on negative space as a practical tool and its potential in the visualisation of weave structure. This reflective chapter serves as a groundwork for case studies (i) and (ii), which respectively explore negative space as a 'structure unit' and through the 'repeat' — presented in the succeeding chapter (05).

Heavily underpinned by Ingold (2007, 2009, 2010, 2015), Dormor (2020) and Igoe's (2011) thinking on materials and textiles, the chapter begins with an exploration of the notion of materiality to illustrate negative space as a 'material' surface — one in a different state than the one of yarns. Barad's (2012) semantic reflection on nothingness and thus the idea of the absence of matter allows the thesis to approach negative space as an entity which, albeit vacant, might have value in a woven construct. Following that is an exploration of negative space in architecture as a hollow yet necessary pillar for solid volumes (Kent Peterson, 1980). The potential of organic, irregular and unpredictable geometric shapes as a source of knowledge for visualising weave structure is then explored though Fractal geometry (Mandelbrot, 1975; Samuel, 2012). Finally, the chapter closes with the study's understanding of negative space as a tool and a lens in order to underpin its use in the practical exploration of weave structures (chapter 05).

4.1 Material space

To speak of woven textiles implies speaking of the 'material' elements (e.g. yarns, threads) of which it is composed. Ingold (2007) writes that materials are "the stuff that things are made of" (p. 1). For millennia, thinking through threads has driven the ways in which weavers construct woven textiles. However, various makers have indeed challenged the traditional principles of the craft. For instance, textile practitioner Peter Collingwood's Macrogauze (1970s) provoked weaving's perpendicular parameter and escaped from it by letting warp yarns angle themselves in such ways that three-dimensional shapes arose (image 4.2). In the same artistic vein, Lenore Tawney (1979) radically rethought ways of using yarns in a woven textile construct by exploring the idea of material performance (image 4.3).

Image 4.2
3D Macrogauze
Peter Collingwood (1970s)

Image 4.3
'Written in Water'
Lenore Tawney (1979)

'Stuff' is often regarded as things that one can apprehend through touch. As Albers (1944) puts it, "we touch things to assure ourselves of reality" (p. 44). And, as exposed in the preceding chapter (03), the hands hold as much knowledge as the brain (Classen, 2005). Textile theorist Claire Pajączkowska (2005) writes on the meaning of 'stuff' by linking it to the French *étoffe*, meaning 'cloth'. That is, woven cloth isn't a ubiquitous 'thing', rather it is a pliable "material matrix" (Dormor, 2020, p. 3).

4.1.1 Surface

In his treatise on the line, Klee (1921-1931) explains that figures take shape through the folding of lines, which itinerance replaces forms by planarity, i.e surface, upon creation. Taking its root from the Latin *linum*, the term 'line' acts as a prime example of weaving and drawing's entanglement (Mitchell, 2006). In fact, Ingold (2010) mentions how Renaissance architect

Alberti argued that the linear character of architectural drawings succeeded warp and weft on tension. As Pajaçzkowska (2005) states, "threads, [...] is not just one variant of line, but its origin" (p. 233). Thus preceding lines, the interlacement of taut verticals and horizontals create the planar surface of woven cloth.

The orthogonal pattern of interlacement on which weaving is founded, inevitably creates empty space in-between warp and weft. This is true regardless of the tightness of the weave structure — together influenced by warp ends' closeness and the beating force applied to weft picks, yarn properties and/or fibre composition. It is therefore accurate to suggest that negative spaces are part of weave structure's topology, meaning that, negative space exists always and forever within a woven textile's surface. Whether or not they are a part of woven cloth is another question. As woven textiles are "material systems" (Tandler, 2016, p. 36), themselves composed of various materials, the study requires understanding the potential 'material' characteristics of negative space. What does it mean for it to be a 'material' surface?

Ingold (2007) reflects on Gibson's (1979) understanding of surfaces and proposes that while they have different degrees of "stability", they are "interfaces between one kind of material and another" (p. 7). He takes the example of rock (solid) and air (gaseous) to explain that as surfaces they are both materials that exist in different states. He writes that one can touch the rock to understand "what rock is like as a material" (p. 7). But, the "materiality" of the rock isn't graspable. In that the materiality of surface is "an illusion" as one "cannot touch" what "is not there" (p. 7). With respect to weave structures, this confirms that woven cloth is composed of different surface materials, i.e. solid (warp and weft) and gaseous (negative space) ones — proposing that, albeit intangible, negative space is a 'material' component of weave structures.

4.2 'Absent' space

Negative space in woven cloth is seemingly 'not there', that is, absent, which hinders the comprehension and ascertaining of its role. By this the research means understanding its 'material' content as opposed to its state, and hence need in weave structure visualisation. Yet as a 'material' space in the Ingoldian sense of the term, it must be something, or at least, a peculiar form of 'nothing'.

Semantics plays an important role in establishing a conceptual understanding of negative space. Writing on ways to measure 'nothingness', Barad (2012) begins with the admission that naming the term 'nothing', directly alters its condition of being 'empty'. Here entering the philosophical realm, López-Marcos (2017) endorses this by referring to political and social theorist Diana Coole (2000, cited in López-Marcos, 2017) who, like Barad's (2012) idea of 'nothing', proposes that verbalising 'negative' annihilate its meaning. In effect, in addressing negative space as an 'absent' space — a non-physical area only visible because of its bordering threads — this

research considers it as something that is 'not'. This is not to refute its 'material' condition. Rather it validates negative space as an entity in its own right — one in a different state than what could be called 'nothing'; thus confirming the relevance of investigating practically its surface content, in order to grasp its possible role and value in weave structure visualisation (chapter 05). Ingold (2010) names "material" what Deleuze and Guattari's (2004, quoted in Ingold, 2010) advance as "matter in movement, in flux, in variation" that is, a "matter-flow" (p. 94). Following this rationale, negative space as a material surface cannot be an area totally deprived of matter, a nothing. Now, this thesis is by no means a philosophical reflection on 'nothing'. As such, following the idea that naming negative space jeopardises its primal state enables its consideration as a part of weave structure.

4.3 Constituent part

Miller (2005, cited in Song, 2014) suggests that material carries the idea of artefact. As well as being a cultural and historical object, an artefact is, from a scientific viewpoint, something that when observed is not obviously present but appears as a consequence of its physical investigation. It is only upon closer observation that one can comprehend its material nature. This definition aligns with the idea that as negative space is examined, its character in weave structure visualisation gradually unfolds.

Elkins (2000) explains that "struggling with materials, and not quite understanding what is happening" (p. 19) relates to a mystical process of creation. The making of negative space is not magical. It emerges from the systematic interlacement of warp and weft. But to affirm that negative space is a part of weave structures implies that it carries a specific function. It is a struggle to ascertain the role of empty space without entering the nebulous world of speculative thinking. Chapter 03 (section 3.2) mentioned that raw material and yarn's functional properties and aesthetic qualities influence woven cloth's behaviour. For instance merino wool provides incredible insulation while maintaining breathability. Yet, weave structures, i.e. the ways in which components are assembled, equally determine how woven cloth behaves (Tandler, 2016) (chapter 03). Thus negative space must hold the same status as warp and weft, that is, a constituent part of a woven textile, hence weave structure. Now, one must ask whether such a space can be understood within the geometric grid, by which the current weave structure notation abides.

4.4 Geometric shape

Humans commonly consider the unpredictable as unruly, leading us to seek comfort in the reassuring foreseeability of mathematical order. In *The irregularity of reality*, Buchanan (2011, p. 184) rightly indicates that humans long for and "expect regularity in everything". "Euclidean and Cartesian simplicity" (p. 184) is often assumed to be 'more efficient', even if it is well accepted that irregular and fluid structures inspired by nature are more effective. Based on the Cartesian grid, the current weave structure notation geometrically rejects nonlinear and chaotic forms. Yet, as Hayles (1991) writes, the necessity and violence of chaos "challenges and complements the transparency of order" (p. 3). In what follows, negative space is explored as an irregular and unpredictable shape yet intrinsic to geometric stability.

4.4.1 Negative space in architecture

Kent Peterson (1980) coined the term 'anti-space' as the antithesis of space-as-idea. To borrow his words, the former is "undifferentiated, [...] infinite, [...] continuous" while the latter is "differentiated, [...] finite" (p. 3). This antithesis, he explains, stems from an analogy to the scientific definition of the Cartesian grid (López-Marcos, 2018). He goes on to assert that although both spaces exist, they cannot coincide. This is connected to weaving because as stated in chapter 03, the craft embodies the paradox of inflexibility of construction methodology against fluidity of its product, i.e woven cloth. Thus to rectify the space/anti-space opposition, Kent Peterson (1980) proposes that negative space, i.e the empty space in-between walls, can be added to spatial structuring. He specifies that it should not be seen as an unusable gap. Rather, as it occupies space in a different "condition" (p. 6) than positive space (solid), it acts as "necessary backup for the larger geometric volumes" (p. 6). Collocated to woven cloth, this puts forward negative space as a non-solid pillar for the matrix of interlaced yarns thus substantiating its notability in weave structure and potential functionality as a practical tool in visualisation.

This idea of negative space is interesting in regards to drawings in architecture. For Kent Peterson (ibid.), "habitable poché" (p. 6), is the drawn negative space that appears as a solid limit giving form to positive space (image 4.4). Yet, its empty nature simultaneously generates ""hidden" place within itself" (p. 7). This suggests that, in regards to weave structure notation, negative space is both a supporting element to warp and weft and a space within which things can occur. In other words, here, negative space's 'emptiness' permits occupied space to behave. As a result, one can attest that as an inherent component of weave structure, it is worthy of being considered in the notation system. However, as an irregular, organic and unpredictable shape, it cannot be understood by means of the x; y coordinates plane and asks, can it be understood within the geometric grid? Thus research turns towards fractal geometry to understand how its chaotic nature might be beneficial to visualise it.

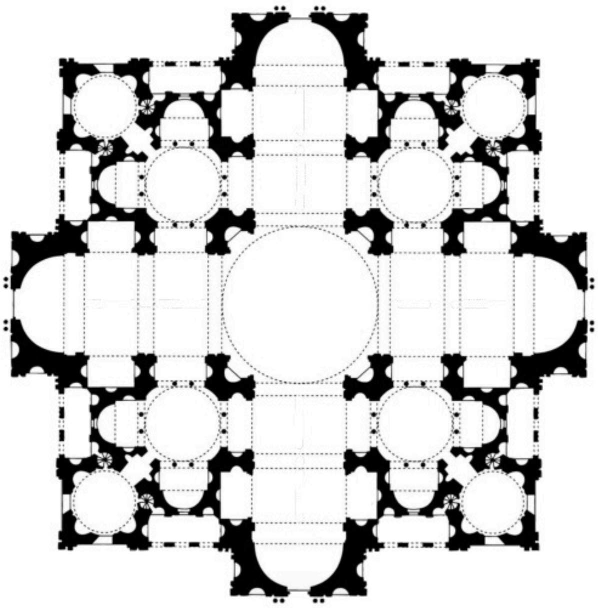


Image 4.4
Early Plan, St Peter's Rome, Bramante, circa 1506
Image from Kent Peterson (1980, p. 6)

4.4.2 Fractal view

From an observation of natural occurrences, and specifically the coastlines of islands (Samuel, 2012), Mandelbrot (1975) theorised fractal geometry. As a "new geometric language" (Mandelbrot 1975, quoted in Samuel, 2012, p. 29), it is an aggregate of points, lines, surfaces "loosely characterized as being violently convoluted and broken up" (p. 20) (image 4.5). Within a weave structure, negative spaces are separate fractured elements which together appear to be part of the harmonious continuum of woven cloth (chapter 05).

The study of negative space by means of fractal geometry would be an interesting venture. However, this research doesn't intend to study the hole's technical characteristics as a singular entity. And, while case study (i) (chapter 05) undertakes a practical examination of its borders-surfaces, it does so in order to understand the potential of its use as a tool to visualise weave structures. In effect, the definition of fractals as a seemingly chaotic accumulation of ruptured 'things' enables a conceptual outlook on the geometric matrix. In other words, it illustrates the need to forgo perceiving weave structure notation through the Cartesian grid's perspective, that is, as a manufacturing tool.

As Wolfe (2014) states, breaking away from the orthogonal plane means following "organic continuity" (p. 05). Consequently and thus far, the notion of fractal geometry serves as the groundwork to approach negative space as a fractured shape unable to fit in square boxes and understand its spatial formation within weave structure.

Image 4.5
'Benoit Mandelbrot "Erroneous" and "destroyed" version of the Mandelbrot set 1982 Computer graphic on photographic paper, torn, stained and signed Collection Aliette Mandelbrot'
Image from Samuel (2012)

4.5 Tool and lens

From a mechanical perspective, tool and lens share the idea of instruments, in that they carry a particular function, which answers to specific mechanical parameters. Because empty space isn't solid, the study probes whether, as a tool, the non-physicality of negative space can be considered as a source of new knowledge and as a means through which to develop a new understanding of weave structure visualisation. Sennett (2008) writes:

> Getting better at using tools comes to us, in part, when the tools challenge us, and this challenge often occurs just because the tools are not fit-for-purpose (p. 194).

Ingold (2011) points out that it is common belief to attest that using tools must reflect the practice of a technology, i.e. the process of doing or making. Yet he questions this presumption by suggesting that making things with tools might not be "the operation of a technology but [...] an instance of skilled practice" (p. 294). With this in mind, regarding negative space as a tool might enable moving away from understanding weave structure notation as a manufacturing tool and in turn weaving as a design method. Additionally, by taking the epistemological view of Polanyi on the tool as an instrument of knowledge excavation and applying it to the study, the research understands the term's unmechanical nature as an apparatus that goes beyond the mechanical.

Although Barad's (2012) conception of measuring a vacuum, i.e. 'nothingness' pertains to quantum philosophy, she proposes that measuring is a performative practice in which the tool holds a dual status. It is both an element of what is being measured and an agential apparatus for measuring. Here 'measuring' doesn't refer to quantity. Rather, negative space as tool and lens maintains this duality. By this the research means that it is both the practical instrument with which weave structure is visualised and a mediating lens through which to develop an alternative perspective on notating weave structure.

05.

‘structure unit’ & the ‘repeat’

CASE STUDY (i) & (ii)

05. 'Structure unit' and 'repeat'

This chapter covers two experimental case studies. They are experimental in that weave structure visualisation is explored through the practical manipulation of negative space. Case study (i) identifies negative space as a 'structure unit'. Case study (ii) analyses it within the 'repeat'. Both studies employ weaving, drawing, microscopy and X-Ray CT scanning as media-methods because they are as much an act (medium) as well as a way (method) of examining negative space. Led by practice, research respects a to and fro approach between each method, facilitating an intuitive yet objective analysis of practical data.

5.1 Case study (i) — exploring negative space as a 'structure unit'

The first case study sets out to explore negative space as a 'structure unit' in weave geometries, in order to uncover its potential practical characteristics, value and role in weaving's notational system. To begin, the idea of 'structure unit' is introduced.

5.1.1 The 'structure unit'

In weaving, the 'structure unit' is a repeatable sequence composed of a specific number of ends and picks (at least two) and notated with black and white squares within an orthogonal matrix. The amount of warp ends and weft picks vary depending on the structure and may be equal or unequal, yet forming a full rectangular grid-like plane (Watson, 1912). For instance, a 2/2 twill involves a 4 ends/4 picks sequence (figure 5.1), which repeats itself throughout the width and length of the fabric, to form a complete woven cloth.

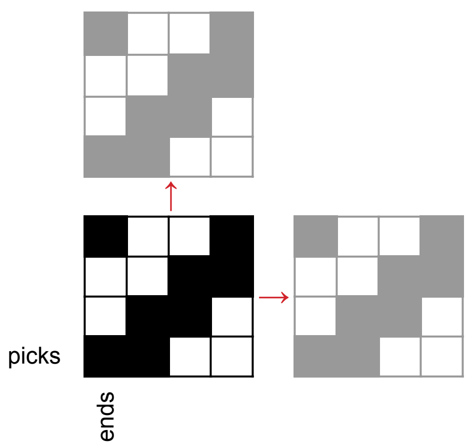


Figure 5.1:
Weave structure notation of a 2/2 twill
Ariane Fourquier (no date)

Outside of weaving, a 'structure unit' is broadly understood as an individual, entire entity which can also be a single element of a wider and more compound whole. This definition underpins the study of negative space as a 'structure unit'': that is, an individual yet complete entity within a full woven matrix. Additionally, a unit is an apparatus with a specific function, one part of a complex mechanical system (Watson, 1012). While the overarching scope of this research is not solely engaged with negative space, it is crucial to understand it practically as an entity in its own right. This is because negative space is employed as a practical tool (chapter 04) through which to explore weave structure notation.

5.1.2 Aims and objectives

The first case study aims to identify, observe and draw out negative space's characteristics as a weave 'structure unit'. The objectives are as follows:

(1) **Investigate the technical and aesthetical characteristics** of negative space in order to identify it as an entity, albeit in an insubstantial material state, and observe its behaviour at different scales, i.e. macro, micro and nano scales.

(2) **Question its role and value, if any, as a 'structure unit' in weave structure topology** in order to proceed with case study (ii), i.e. investigate its function in the 'repeat'.

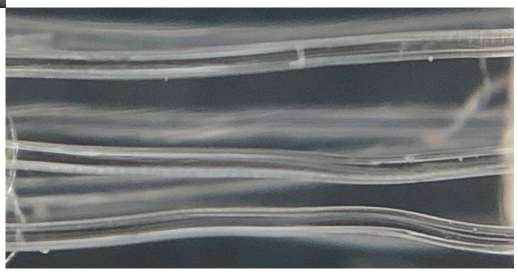
(3) **Visualise negative space as a 'structure unit'** and explore what it can uncover in the ensuing development of a new weave structure visualisation.

5.1.3 Weaving practice

Rooted in practice, the study required specialist technical knowledge and experiential 'know-how' (Polanyi, 1966) of weaving principles and processes (chapter 03). Originally, textiles' properties were majoritarily qualified by yarn properties (Emery, 1966; Tandler, 2016). While yarns are not the primary focus of this study, it is noteworthy that depending on spinning techniques and raw materials, the qualities and functions of yarns are myriad. There exist different spinning techniques. Extremely simplified, fibres either follow a Z twist — to the left — or S twist — to the right —. Depending on the twist, and the type of fibre(s) used, a staple yarn holds different aesthetic and functional properties. However, no yarn is ever completely regular, in the sense that fibres' behaviours and properties abide by the process in various ways. For instance, mohair fibre appears fuzzy because of small woolly tufts. Once spun, some fibre particles 'escape' from the yarn axis while remaining entwined to it, giving an irregular floccose characteristic (image 5.1). Other types of yarn can also be extruded, which involves complex chemical processes of raw material then pressed into a spineret. This process produces more uniform, smoother threads (e.g. celluloid monofilament) (image 5.2).

Image 5.1
Microscopy of mohair yarn
Ariane Fourquier (2023)

Image 5.2
Microscopy of celluloid monofilament
Ariane Fourquier (2023)



Woven textile's properties don't only depend on the yarns with which it is constructed, in that they also rely on the weave structure design (chapter 03). To create a sturdy and stable cloth, appropriate yarn spacing must be established when designing a warp (Meredith and Hearle, 1959, cited in Tandler, 2016). The closer the warp ends, the denser the cloth. Because of its lightweight open nature (Emery, 1966), leno weaving facilitates creating empty space within the weave structure (chapter 02, section 2.7.1) while maintaining cloth's stability. This is due to the technique's construct, which necessitates intentionally leaving gaps between ends, a parameter controlled by the threading of the reed — a comb-like device used to beat each weft pick. Contrary to most weaving techniques, which requires warp planning by counting the number of ends per inch or centimetres, leno structure needs to be calculated in packs of warp threads (Watson, 1912).

Having never experimented with leno before, my specialist knowledge of 'traditional' weaving technique (e.g. adequate for simple and compound structures) wasn't applicable. First attempts resulted in a dense cloth in which ends struggled to twist around each other (image 5.3). While gaps were visually apparent, the cloth's robustness was compromised. In addition, leno weave structures follow the same notational system as other structures (e.g. twills). However, the black/white squares formation does not suggest the corresponding textile appearance (e.g. diagonal lines). This can easily confuse both novice and experienced weavers, let alone designers from other disciplines. As such, the current notation requires a substantial degree of intuition and tacit knowledge to create leno textiles and overcome technical and creative problems (figure 5.2).

5.1.4 Methods, media and instruments

Each method used different media and instruments, allowing an observation of negative space under different scales and perspectives (chapter 02). In this thesis, weaving, drawing, microscopy and X-Ray CT scanning have double value. As methods, they are techniques, that is, specific and systematic ways of doing. As media, they are activities, that is, means of doing, in the technological sense of the term. The notion of medium is vast. As such, this thesis keeps to the idea of activity. Heinzel (2012) explains that a medium acts as a vehicle for the ensuing product, i.e. the 'content', to be formed. She adds that the "notion of medium is linked to the devices' materiality" (p. 187), that is to say, the tools with which a thing is made. With this in mind, all methods, as well as being techniques of production, are channels for the 'content', that is, the surface of negative space as 'structure unit' to be studied. And, because it is used as a tool, visualising its surface and analysing its properties is necessary to understand its role and value as a vehicle for notating weave geometries.

Equally, negative space isn't the sole instrument of this study. The practices' apparatuses, including hands, loom, pencil, microscope, CT scanner, all imply different notions of physicality. Meaning that their ensuing products exist in the physical — woven textiles, drawings — and the digital realm — microscopies, scans —. At once vehicle and apparatus, method and medium reflect an "extension of man" (McLuhan, 2004, quoted in Heinzel, 2012, p. 189) that is, all that resides "between an idea and its realisation, between a thing and its reproduction", i.e. an "intermediary" (Rancière, 2008, quoted in Heinzel, 2012, p. 187). In studio practice, this meant that the apprehension of negative spaces' practical characteristics within the imagery — sample, drawing, microscopy, X-Ray CT scan — was influenced by the media's materiality. That is to say, the physical and virtual realm offered different lenses to draw out compelling insights, enabling an interplay between subjective and objective analysis. This is explained below.

Image 5.3
First attempt at leno weaving
Ariane Fourquier (2023)

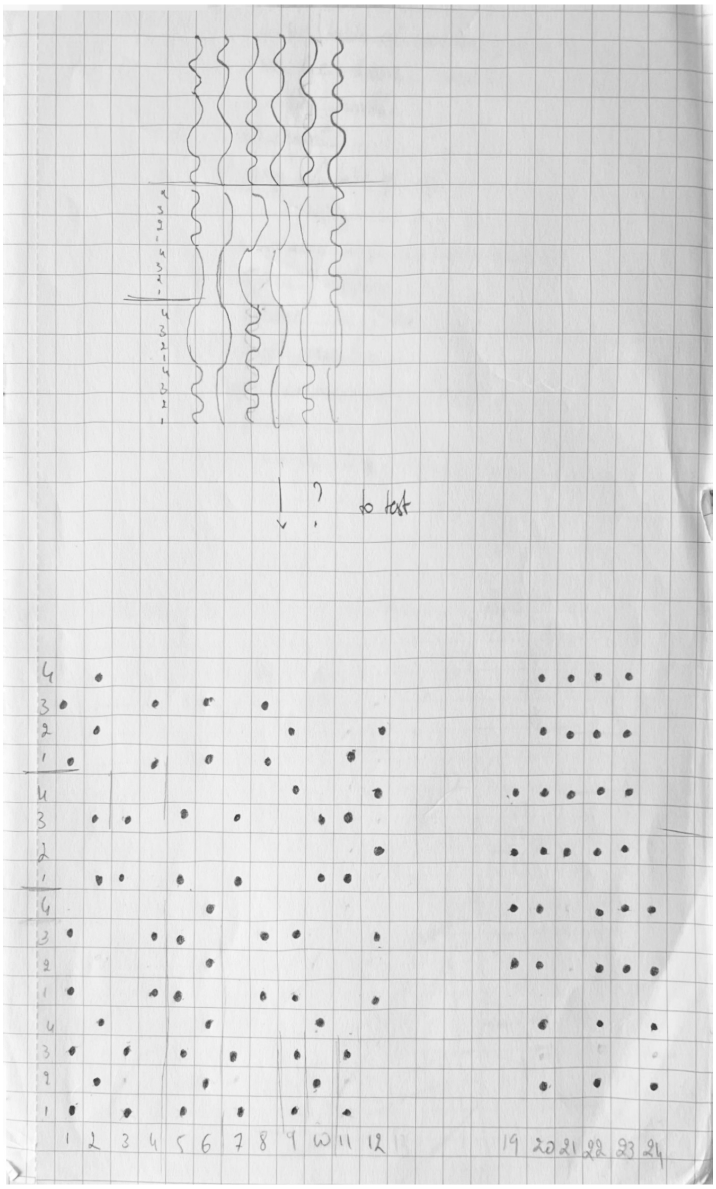


Figure 5.2
Drawings attempting to translate leno design into a notatition fit for the machine
Ariane Fourquier (2023)

5.1.4.1 Weaving and the eye

Weaving was conducted on a Handloom Holdings Ltd. ARM Touch 60 loom, which is an electronic treadle loom (image 5.4). Those machines are floor looms and actuated by the weaver's feet, which manipulate the pedals, raising or lowering the shafts. Each warp thread is threaded through a heddle, itself attached to a shaft; both vary in number, depending on the threading plan. Leno weaving requires two warps: one leno warp, that twists around the 'straight' or 'non-weaving' warp, which remains stationary and usually mounted on the last shaft (back of the loom). The threading of the leno warp needs two shafts. One (behind the first shaft) carries a soft, loop-like device, called doop. The doop goes through the front shaft's heddle and each leno end is passed through the second heddle and doop (figure 5.3). These lift the leno ends, letting them twist around their neighbouring 'straight' ends. The doops, made of coloured cotton yarns, were 14.5 cm folded and of identical size for this study (image 5.5).

Image 5.4
Arm Touch 60,
Image from Handloom holdings Ltd (no date)

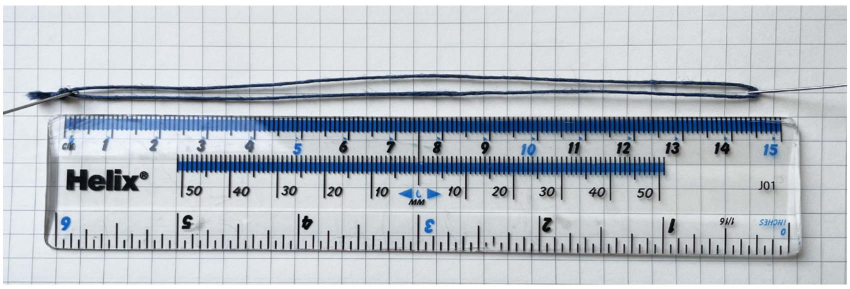


Image 5.5
Doup used for leno woven samples
Ariane Fourquier (2023)

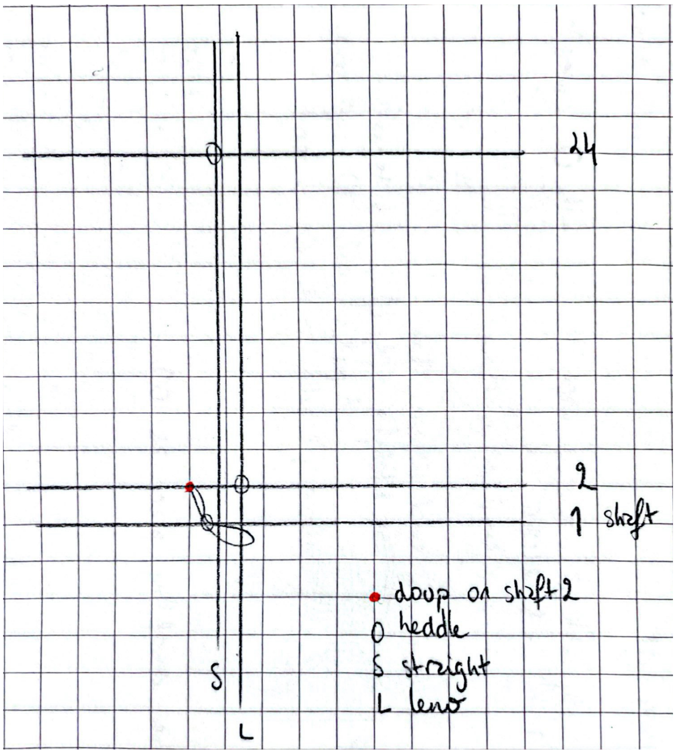


Figure 5.3
Leno set up on the loom
Ariane Fourquier 2022

An extensive library of fifty woven textile samples was made. Observations of negative spaces by means of the naked eye, separated the entire repository into three groups, namely, 'squares', 'triangles' and 'other shapes'. Among all samples created, each set was narrowed down to five ('squares') and four samples ('triangles' and 'other shapes') to focus the study (images 5.6 to 5.18, pp. 77-79). Because negative spaces' exact aesthetic and technical characteristics were unknown at this stage, this differentiation was based on an observation of the yarns used. The reasoning was as follows:

- Yarns' aesthetic and mechanical properties.
- Threads' pattern of interlacement, i.e. leno weave structure designs.
- Samples' visual and tactile characteristics — e.g. fuzziness, roughness, shape, drape, look and handle —.

Each group included one industrial sample because these are woven with greater accuracy under various parameters, such as warp tension or weft placement constancy (through automata's regular beating force). This apparent uniformity needed to be verified and compared against hand woven negative spaces, which was particularly relevant within a repeat in case study (ii).

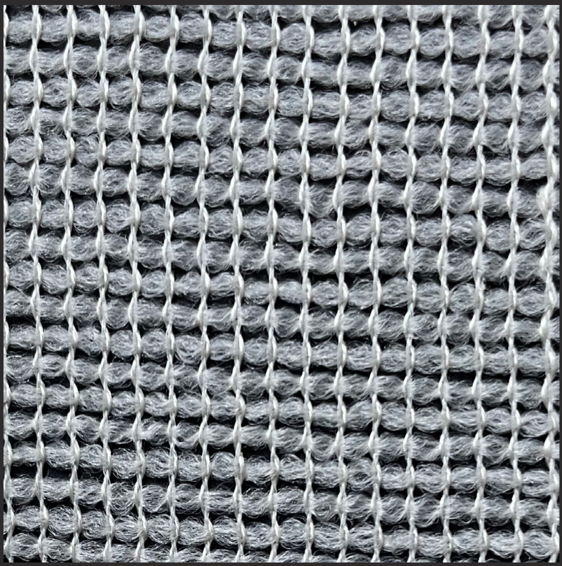


Image 5.6
woven sample S1
Ariane Fourquier (2023)

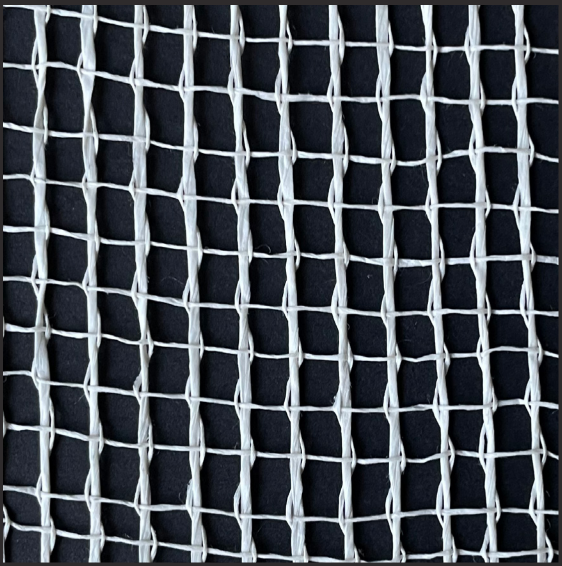


Image 5.7
woven sample S2
Ariane Fourquier (2023)


Image 5.8
woven sample S3
Ariane Fourquier (2023)

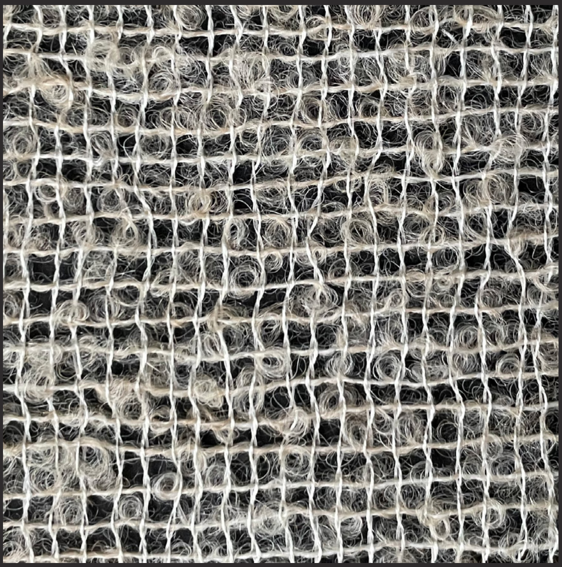


Image 5.9
woven sample S4
Ariane Fourquier (2023)

Squares

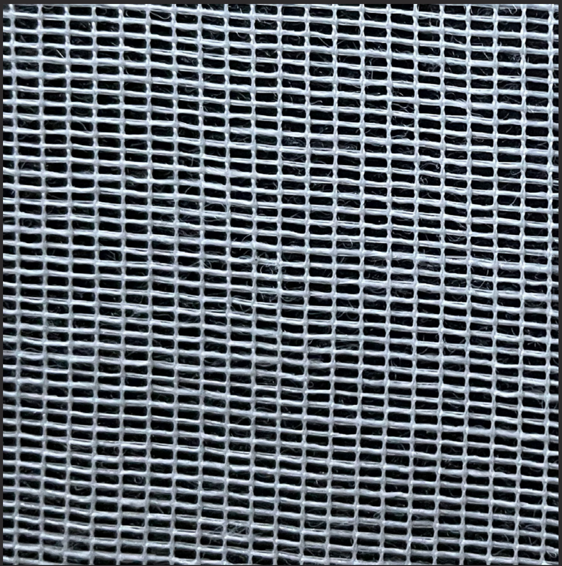


Image 5.10
woven sample S5
Ariane Fourquier (2023)

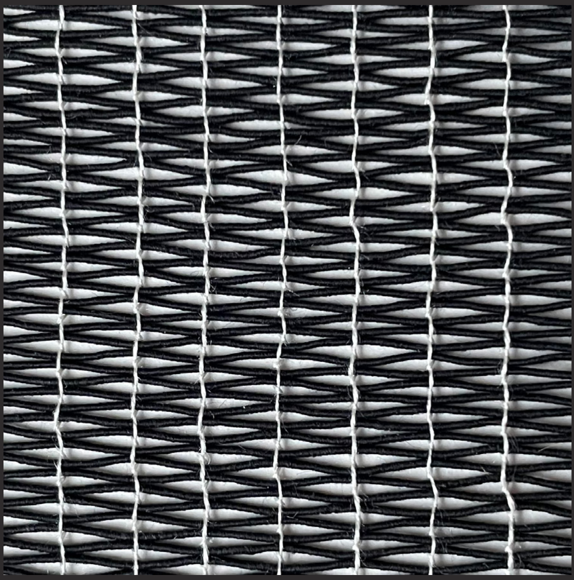


Image 5.11
woven sample T1
Ariane Fourquier (2023)

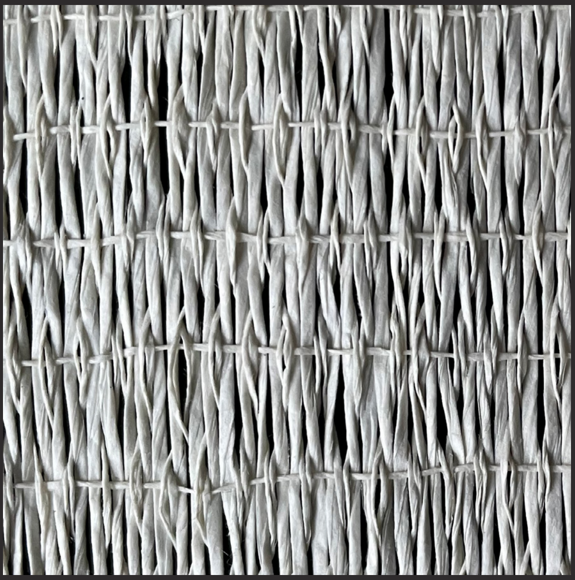


Image 5.12
woven sample T2
Ariane Fourquier (2023)

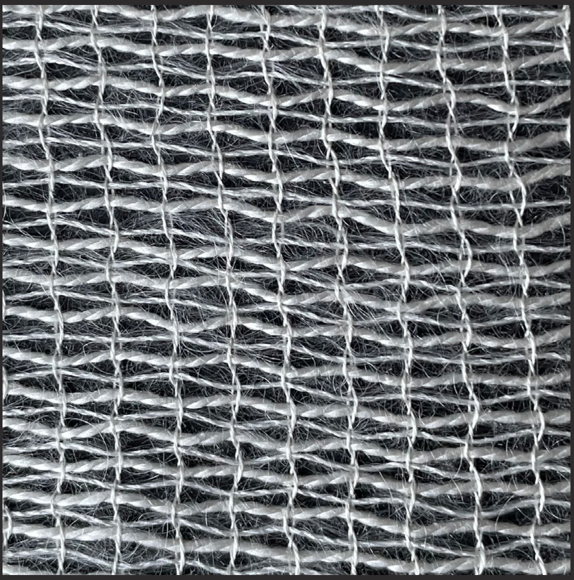


Image 5.13
woven sample T3
Ariane Fourquier (2023)

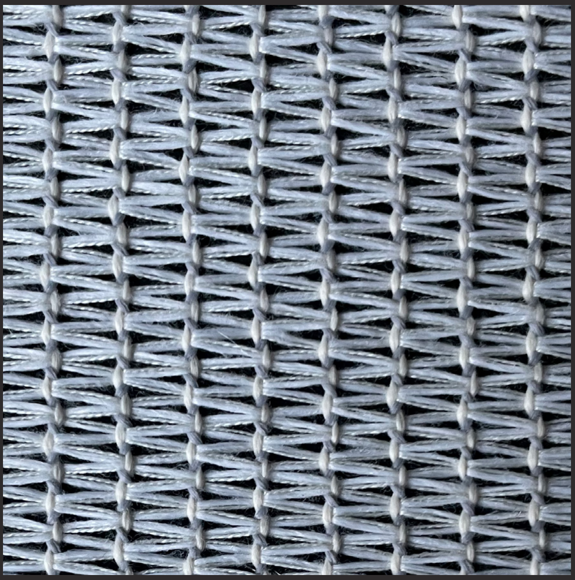


Image 5.14
woven sample T4
Ariane Fourquier (2023)

Triangles

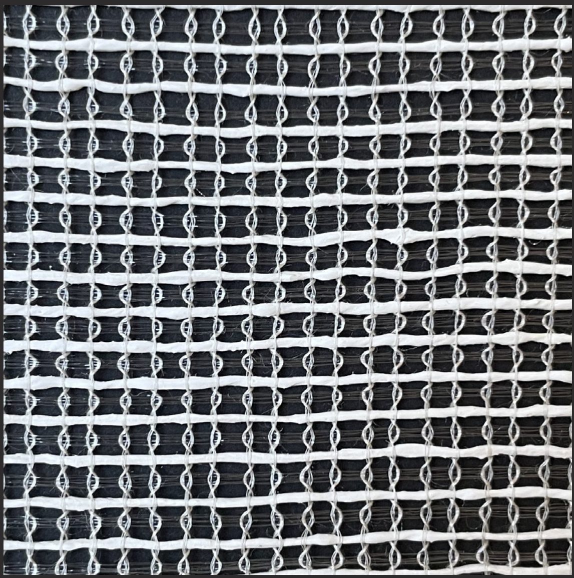


Image 5.15
woven sample O1
Ariane Fourquier (2023)

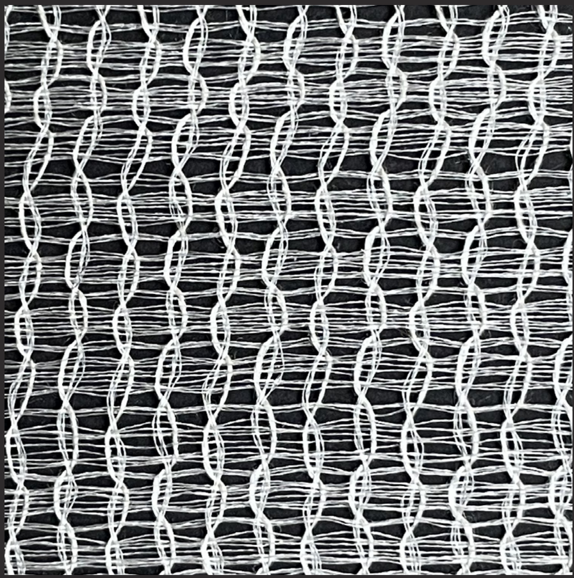


Image 5.16
woven sample O2
Ariane Fourquier (2023)

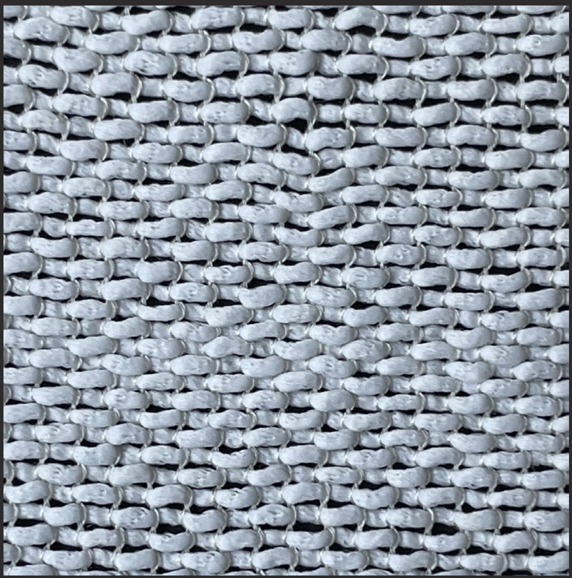


Image 5.17
woven sample O3
Ariane Fourquier (2023)

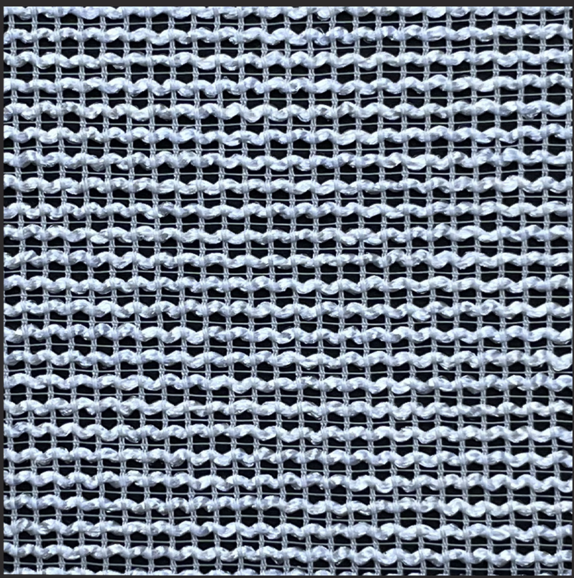


Image 5.18
woven sample O4
Ariane Fourquier (2023)

Other shapes

Yarns were kept as acquired, because dyeing them would have distracted the identification of negative space's qualities and properties. The samples' technical specifications, i.e. warp composition, yarn count, drafting and lifting plan, can be found in Appendix A. Once off-loom, the samples were processed, i.e. washed and ironed, to release tension and loosen textiles components and structure, hence letting the woven matrices shape themselves naturally.

Although humans' visual perception of things is personal, that is, one does not discern things in identical ways as one's neighbour, it is also universal and direct. Meaning that sight allows a common apprehension of the object of study. In other words, the eye is a tool that facilitates a direct, objective vision of negative space at the macroscale, hence a common understanding of negative space's approximate characteristics.

5.1.4.2 Drawing and hand

Drawings illustrate a three-dimensional entity into a two-dimensional image. Negative space's outlines and content were first drafted, to sketch its borders' boundaries and its surface treatment, respectively. A 3B graded pencil was used because of its soft and greasy nature, in order to visualise negative spaces' content properties: depth and intensity. Drawings were made on a 200 gsm paper: 'Heritage 200'. The cellulose wood pulp paper has a vellum surface, rendering a thin yet robust surface with a soft finish. Such a characteristic enables precise and detailed work, adequate for drafting negative space. As a method, drawing gives way both to objectivity and subjectivity in a sense that it can picture a real object while retaining the critical interpretation of the drawer through their gesture (chapter 02). Drawing as a medium can be approached in two ways: material and practical (representation), or phenomenological and materialistic (performance). The former accord the hand a status of instrument (Leader, 2016), that which is an extension of the drawer's thinking mind. In simple terms, hand sketches the image as it is seen, exhibiting the material characteristics of the entity. The latter still perceives the hand as an instrument but its movement is only made possible by something external to the drawer, i.e. a "remote will" (Klee, 1918, quoted in Healy, 2022, [no pagination]). The drawer and its subject are individuals but inseparable and their coexistence accord material characteristic and affordance to the drawn entity. As such, drawing-as-performance and drawing-as-representation are intertwined by the hand: both a tool with which to draw negative space and a lens through which to interpret its 'material' condition (chapter 04).

5.1.4.3 Microscopy and lens

Microscopy is a photographic image taken through a microscopic lens, which is usually employed to observe infinitesimal entities. To examine such structures at an adequate scale for analysis, the instrument increases their size, depending on its capacity of enlargement. For this study, microscopies of x200 resolution — measure expressed in linear units (μm) — imparted accuracy and objectivity to identify negative space's minute details. An optical, or light microscope, attachable to a phone was used, meaning that a glass lens enlarges the entity (image 5.19). As with drawing, it depicts a flat view of a three-dimensional cloth in two-dimension, but within the digital sphere.

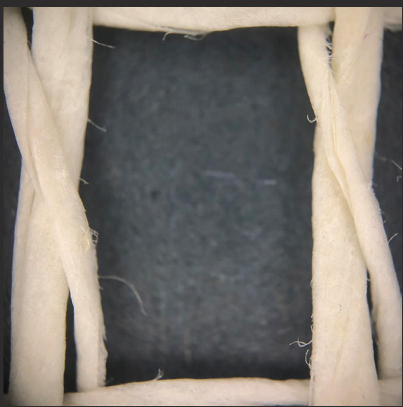
For each sample, the unit studied was selected at identical locations: two inches in from the top and the left, allowing rigorous and accurate comparison between samples (figure 5.4). Additionally, because of the device used, the lens needed to be directly in contact with the sample, leading to a slight distortion of threads' natural behaviours. For instance, Itaca Nm 14 100% viscose's aerated quality (image 5.20) was partly compressed by the lens, hence faintly disturbing its original state.

Image 5.19
Optical (light) microscope
Ariane Fourquier (2023)

Image 5.20
Microscopy of Sample S1
Ariane Fourquier (2023)

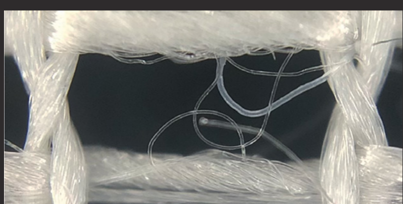
Squares


Sample S1

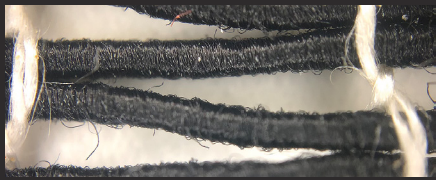

Sample S2

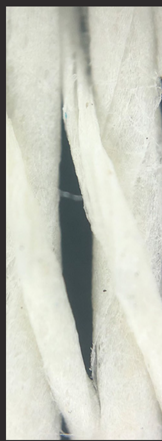

Sample S3


Sample S4


Sample S5

Triangles

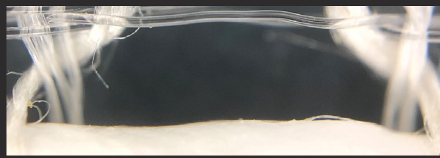

Sample T1


Sample T2

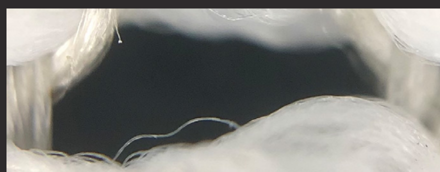

Sample T3


Sample T4

Other shapes


Sample O1


Sample O2


Sample O3

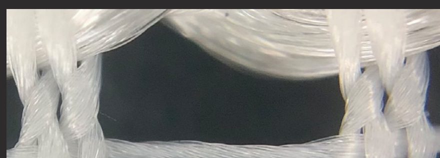

Sample O4

Figure 5.4
Table of microscopies from the 'squares', 'triangles' and 'other shapes' group
Ariane Fourquier (2023)

Likewise, because textiles are moving entities, negative space's outlines were always slightly changing, hindering the apprehension of the entity without intruding on its authenticity. Additionally, with microscopy negative space is only understood through its borders, i.e. threads. Observations first pointed towards yarn's visual characteristics, which delineate negative space, as opposed to its content. This suggested that weave structure visualisation is potentially not strictly ruled by negative space. It also documented the researcher's difficulty to detach themselves from analysis through warp and weft.

In contrast to the naked eye, observation by means of a microscope doesn't allow a direct understanding of the observed entity, rather, one that was made instrument, i.e. mediatised (Heinzel, 2012). Thus, exactness can be challenged. In the sense that, although the microscope pictures a well-defined negative space, its instrumentality obstructs direct observation of the 'structure unit'. In effect, while being the most accurate representation of negative space in this study, microscopy cannot fully escape from subjective perception (chapter 02).

5.1.4.4 CT scanning and X-Ray source

Computer Tomography (CT) scanning was undertaken in partnership with and sponsored by the NXCT lab, at University College London. The Nikon XT H 225, a machine that uses X-Rays to scan entities, offers intricate data of structures (image 5.21). Once processed, slices are digitally stacked to generate a three-dimensional image — giving the clearest picture of the entity's make-up. In simple terms, X-rays are projected through the tubular end of the machine onto the object. When leaving the latter, they are reflected onto the X-ray 'background' source, located opposite to the X-ray tube. Usually placed on a stand, the entity remains flat and static while rotating simultaneously on itself and around an axis, a movement akin to the one of Earth rotation.

Image 5.21
Nikon XT H 225 from the NXCT lab, UCL
Ariane Fourquier (2023)

Each slice can be viewed individually or in a stacked formation. ImageJ — the software used — can only picture scans as a flat image. More complex software can digitally visualise the entity in three-dimension. Prior to being stacked, the slices appear in a chronological order, enabling the stacking of a specific amount of slice or the study of one singular slice — depending on the researcher's intention. For an accurate render, slice selection begins from the apparition of the entity scanned, until its disappearance.

Commonly, the use of X-ray CT aims at picturing small 'solid' entities (e.g. cancerous cells). Meaning that the entity's density/ies are important because X-Rays need to traverse the entity to capture its 'projection', or, 'shadows'. The notion of density in negative space is difficult for thought because its material state isn't solid (chapter 04). The rendered image equally confuses the differentiation of noise — unwanted data — from potential minute particles of matter (chapter 02).

For this reason, sample S3 (image 5.22) was chosen because of the chunkiness and fullness of the weft yarn (Chenille weft yarn Nm 1.6 100% nylon), and hence the size of its negative space. To ensure immobility and thus accuracy, the sample was rolled inside a 5cm foam sheet, allowing it to fit into a cylindrical tube and stand vertically. The image produced was extremely blurred, picturing the textile as if merged with the foam. A second test rolled the sample on itself without any backing. While the image was much clearer, it only permitted picturing the weft's core yarns. The cut pile was barely discernible and looked like a cloud of white speckles, mixed with noise — leading to the quasi-impossibility of discerning the negative shape. Besides, because the sample was curled, the hole appeared distorted and superimposed with other ones (image 5.23). The samples were therefore too big for exact representation of negative space. Aiming to achieve accuracy, smaller samples were cut (1.5x1.5 cm) allowing them to lay flat on the bed, which imparted focus on a single 'structure unit'.

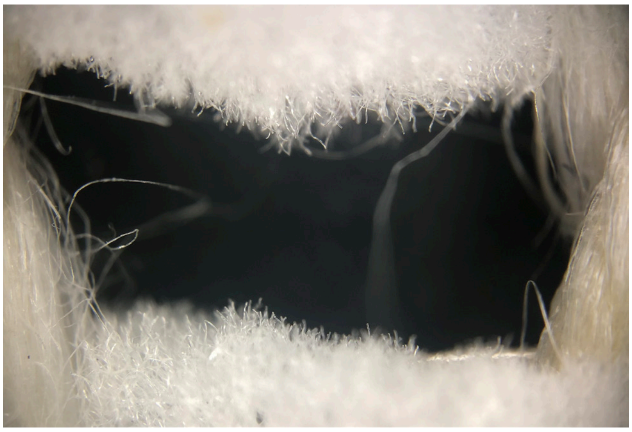


Image 5.22
Microscopy of Sample S3
Ariane Fourquier (2023)

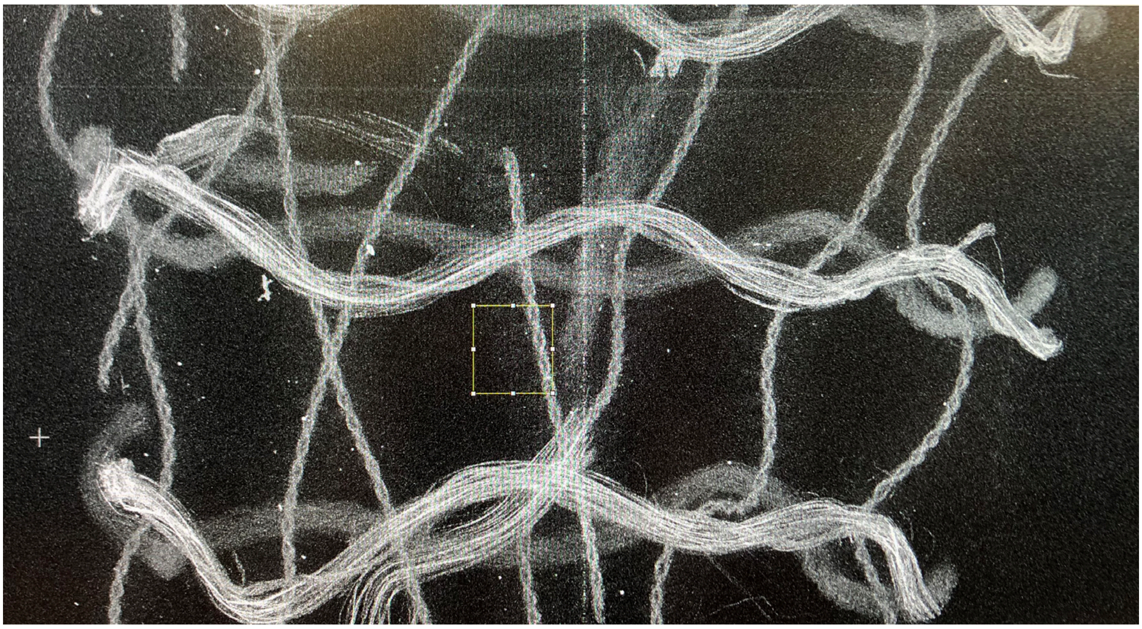


Image 5.23
Sample S3 . First attempt at X-Ray CT scanning
Ariane Fourquier (2023)

In addition to studying the scans as they appeared, research experimented with the software's SUM, MAX and threshold functions. Each slice is equally composed of a set amount of pixels, each of which has a specific value. SUM is the addition of all the selected slices (image 5.24). MAX is the render of an image in which each pixel's value is of highest intensity out of the whole stack (image 5.25). This means that for every pixel, the one with the maximal value is selected to generate a defined and contrasted image. For instance, if a stack is composed of three images and each slice is composed of 4 pixels, the highest intensity for pixel 1, 2, 3 and 4 is selected. The threshold option allows the selection of specific areas of the image — allowing a separation of yarns and negative space (image 5.26). Applying an histogram on the MAX stack provided singularisation of negative space because of the pixel's value, which are either 0 or 1. However, defining negative space's borders is arbitrary because of the fuzziness of material boundaries between occupied (yarns) and empty (negative) spaces — an observation already present at the microscale. This introduced the idea of a possible topology of negative spaces.

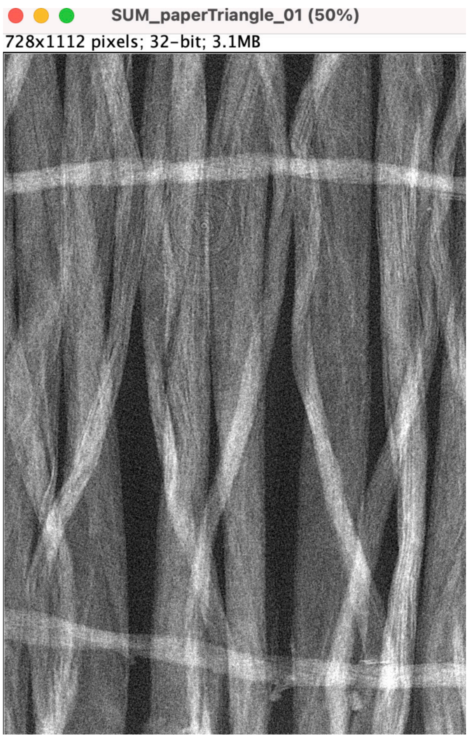


Image 5.24
SUM treatment of Sample T2
Ariane Fourquier (2023)

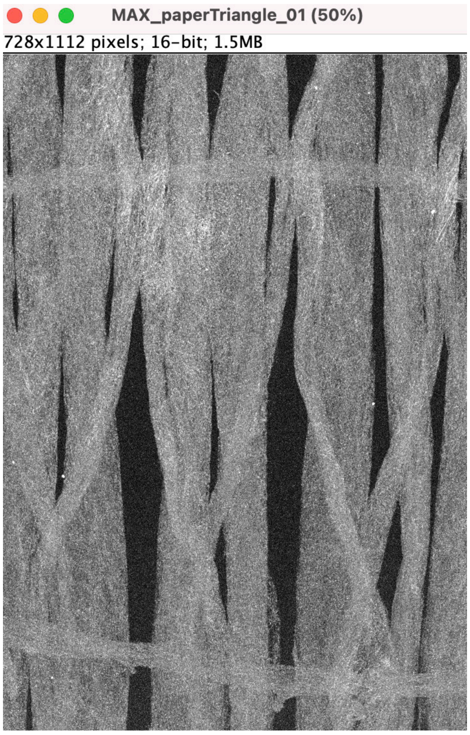


Image 5.25
MAX treatment of Sample T2
Ariane Fourquier (2023)

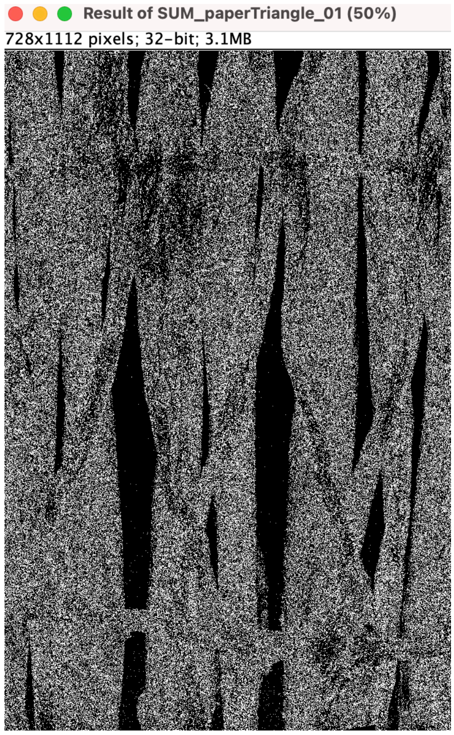


Image 5.26
Result of the multiplication of SUM and MAX treatment of Sample T2 using the threshold function
Ariane Fourquier (2023)

5.1.5 Discussion of findings

Initial observations present similarities and differences between samples. Negative spaces appear similar in regards to their overall shape yet unique in relation to specific features (e.g. outline quality, size). Scale and perspective allows this differentiation.

At the macroscale (eye), negative spaces are seemingly alike, in that their overall rough shape allowed classification into three groups, namely squares, triangles and other shapes. The microscale (microscope) revealed clear borders, which set forth their differences within each group (images 5.27; 5.28; 5.29). Across all samples, independently of which group they belong to, yarns inhabit negative space differently, granting each of them unique characteristics. For instance, silk bouclé imposes smaller holes within the space, nylon chenille cushions its borders, while celluloid monofilament smoothes and ossifies its edges. In a distinctive way, yarns dynamically populate the 'structure unit'. They visually delineate empty shapes and forge their boundaries. This confirmed the singularity of each 'structure unit'.

Image 5.27
Microscopy of Sample S4
Ariane Fourquier (2023)

Image 5.28
Microscopy of Sample T2
Ariane Fourquier (2023)

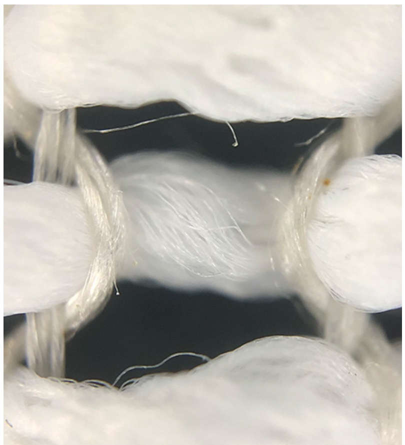


Image 5.29
Microscopy of Sample O3
Ariane Fourquier (2023)

Initial drawings of negative spaces were problematic because they visualised their outlines only (images 5.30; 5.31; 5.32, pp. 88-89). Negative spaces are not 'empty', i.e. deprived of material quality (chapter 04). Rather, they exist under a different state, i.e. a gaseous one, in which 'things' exist but are indiscernible to the eye, and the study's microscope resolution. A much more powerful microscope could potentially identify minute yarn particles or other unknown things. X-ray CT scans however, inaccurately pictured random elements, making it impossible to differentiate between noise or particles of matter. As Heinzel (2012) writes, a surface isn't its sole planar surface but comprises all that is outer, inner and around it. In other words, a surface is composed of its own constituents and everything that it rejects. Following this rationale, albeit a non-physical surface, all unidentified particles compose negative space, regardless of them being within the boundaries of the structure unit's outlines (chapter 04). This evidenced that line drawings do not picture the hole as a surface but simply as a singled out shape. It suggested that line drawing disconnects the hole from other elements of a weave structure.

Additionally, the line is unidimensional, in that it traces the tensions between points (Klee, 1921-1931). Surface on the other hand, is bidimensional in that its existence is caused by the tension between lines (ibid.). In turn, picturing the negative space's content in black, helped understand it as a planar surface and visualise it as a 'material' surface even though it was only depicted in two dimensions (images 5.33; 5.34; 5.35, pp. 90-91). However, it also portrayed yarns as a surface; hence bringing about the notion of empty (negative) and occupied (yarns) space and hinting at a possible interrelation between the two.

The nanoscale imaged negative space with blurred and undefined outlines and content, hindering clarification of the true shape of the 'structure unit'. X-ray CT scans treatments exposed other insights. First the vertical addition (SUM) of all selected slices presented a flat image (similar to a human bone X-ray scan), in which negative space appeared evenly black, occupied space in grey shades. The MAX manipulation pictured better defined forms, yet maintaining the same back/grey colour formation. From the MAX x SUM rendering, i.e an absolute black and white image, the threshold function enabled identifying the possible 'amount' of negative space surface in one unit (image 5.36, p. 92). However, this treatment was very subjective because the differentiation between pixels belonging to empty space or occupied space was governed by the researcher's decision. Thus it was judged too close to personal appreciation of data and inconclusive. While such technical treatments are interesting, they didn't clarify negative space's surface outline or content and are commonly more appropriate for quantitative analysis, which was not applicable for this study. However, this last manipulation pictured some black areas within warp and weft, which corroborated the potential existence of a topology of empty space — an observation true across all samples. Unlike microscopies, X-Ray CT scans are extremely blurry, which hinders accurate localisation of holes within yarns and the point at which empty space shifts into occupied space. While the notion of a possible 'hole topology' can only be speculative, it upholds the idea that negative space isn't a singular disconnected

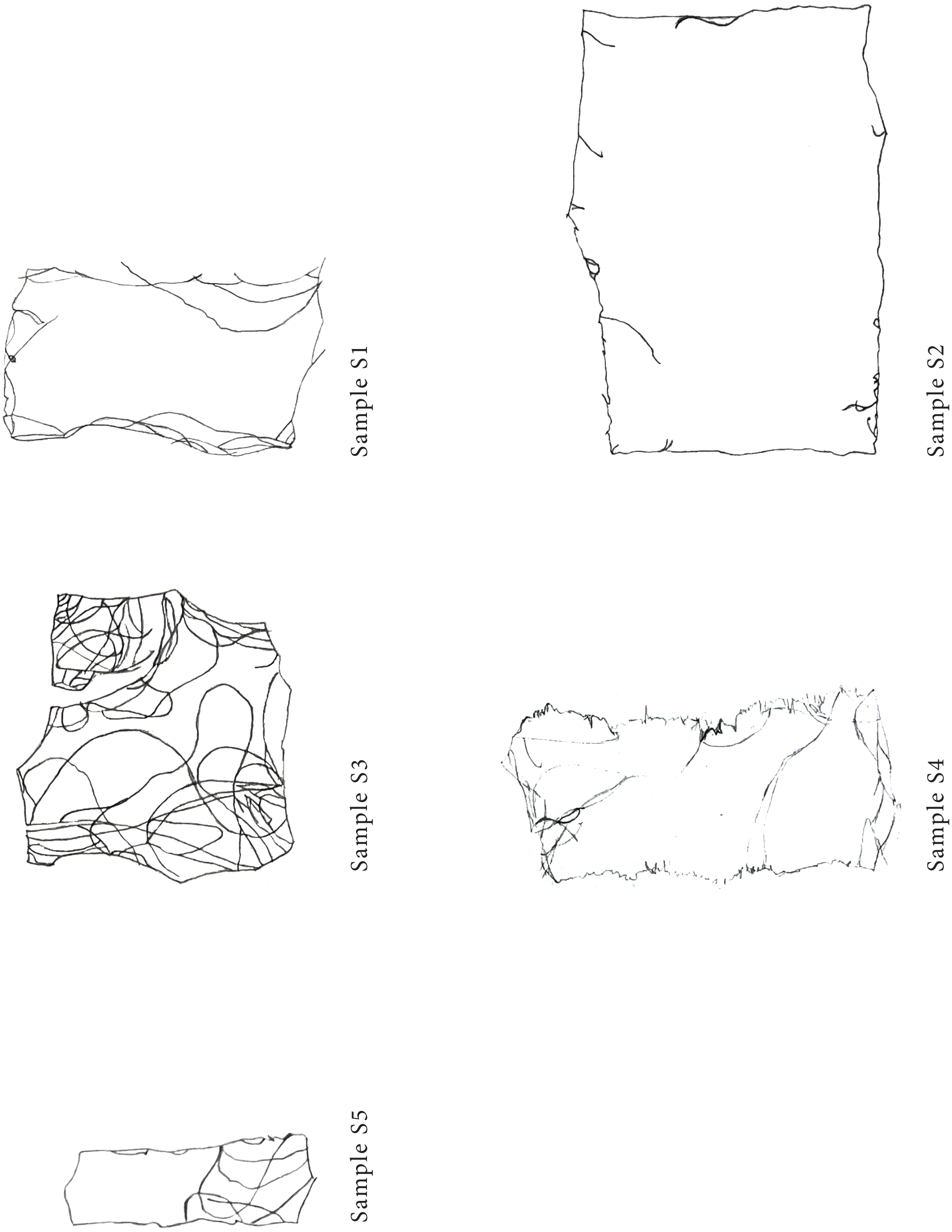


Image 5.30
Line drawings of the 'structure unit' for each sample from the square group
Ariane Fourquier (2023)

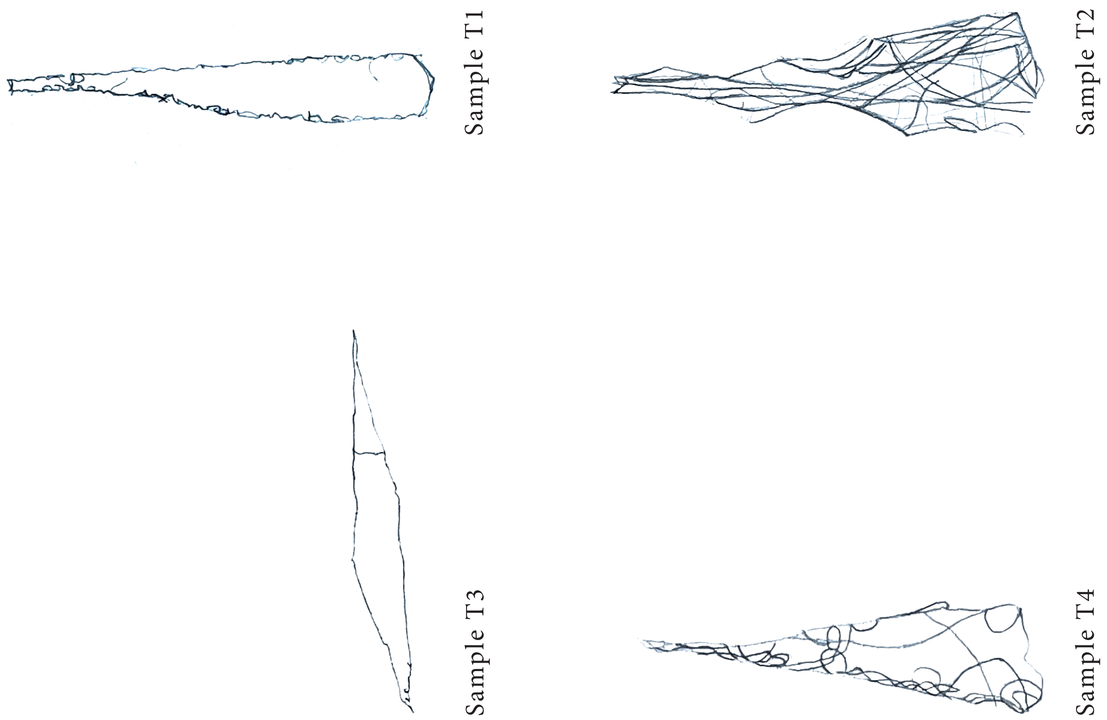


Image 5.31
Line drawings of the 'structure unit' for each sample from the triangles group
Ariane Fourquier (2023)

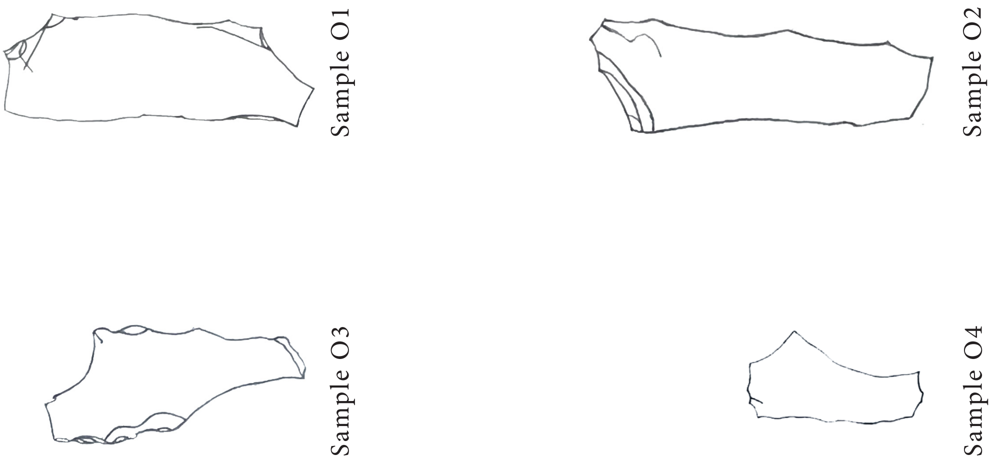


Image 5.32
Line drawings of the 'structure unit' for each sample from the other shapes group
Ariane Fourquier (2023)

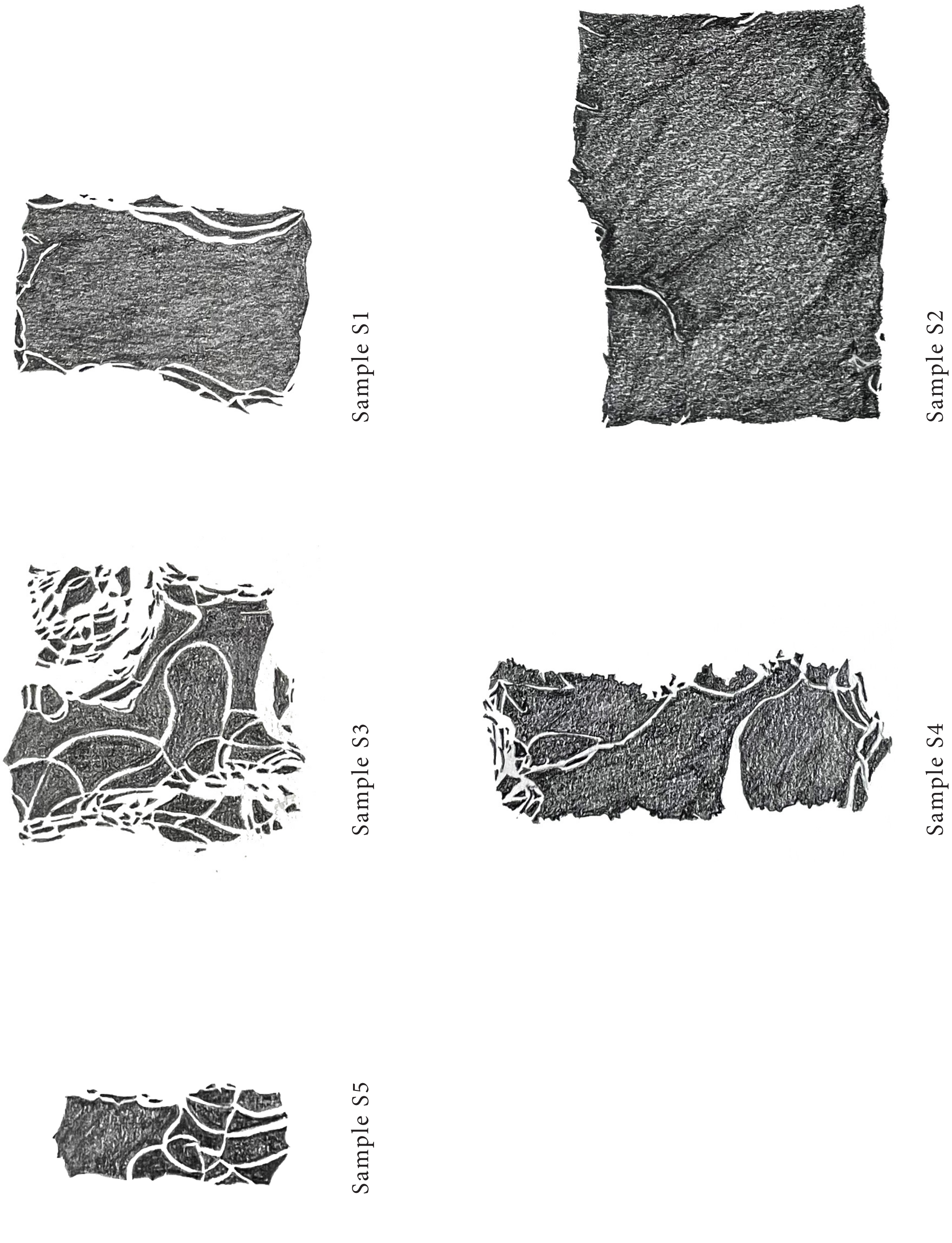


Image 5.33
Drawings of the content of the 'structure unit' for each sample from the square group
Ariane Fourquier (2023)

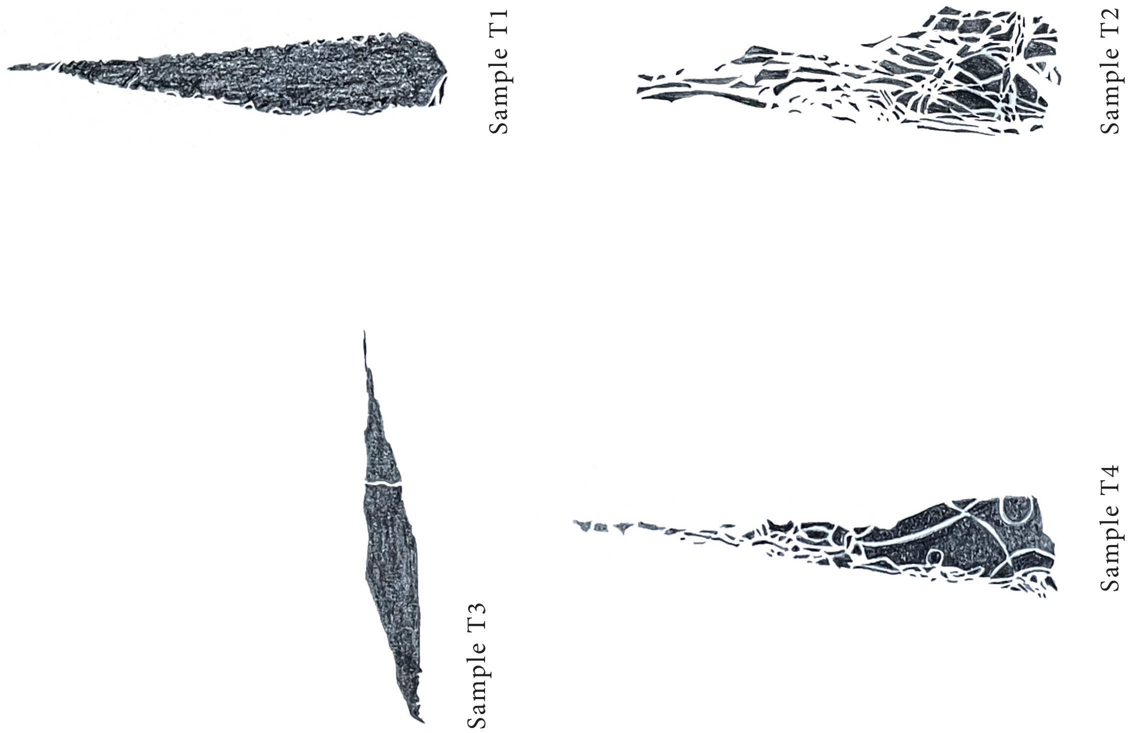


Image 5.34
Drawings of the content of the 'structure unit' for each sample from the triangles group
Ariane Fourquier (2023)

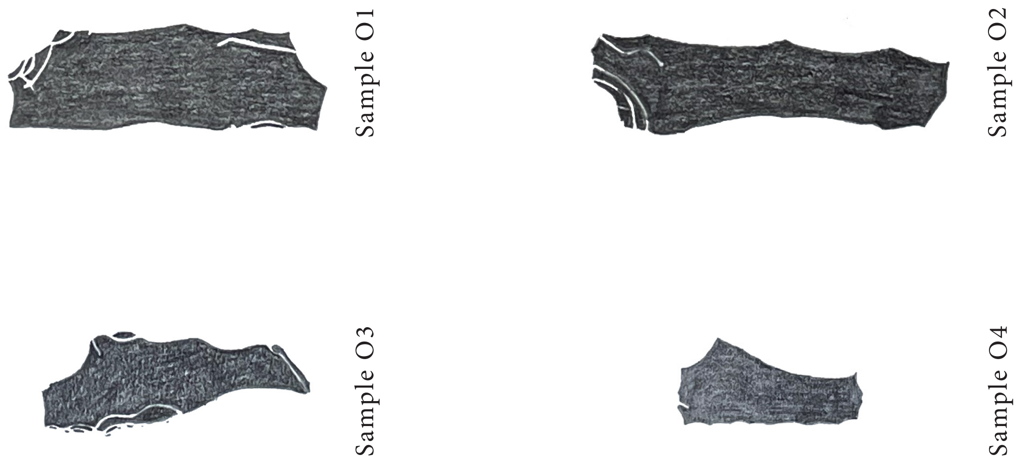


Image 5.35
Drawings of the content of the 'structure unit' for each sample from the other shapes group
Ariane Fourquier (2023)

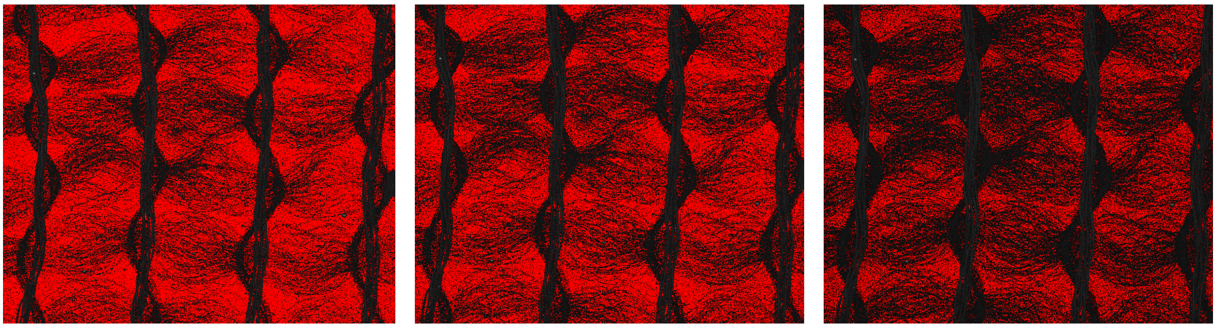


Image 5.36
Selection process of negative space surface area with the threshold function before MAX and SUM treatment
Ariane Fourquier (2023)

entity. Rather, it is part of a system of empty space — one possibly connected to occupied space.

Separately to weaving, each method portrays negative space as a flat entity, this is due to the means of communication used, i.e. paper and computer screen. However, in reality, negative space isn't unidimensional, which poses complex questions. Does negative space's borders stop where threads' diameter ends? Or does the absence of front and back sides suggest that the entirety of the hole has no graspable end? And, is the latter what allows cloth to curve and shape itself into three-dimensional folds, infinitely? While important, such questions imply a phenomenological reflection and could not be answered by any of the methods used, hence belonging to possible future research (chapter 10).

5.1.6 Furthering the study

Visualising negative space as a 'structure unit' revealed compelling insights, including their singularity (e.g. shape, size) across all groups and their approximate similarities which allowed their division into three groups. Black pictured negative spaces' surface and inferred that the study of weave structures cannot operate without considering warp and weft because of their behaviour within the hole, and their ability to shape its borders.

In weaving, a 'structure unit' refers to a full weave structure, also known as a 'repeat'. These represent threads' pattern of interlacement, which are identically repeated throughout the length and width of the textile. As such, negative space must be investigated within a weave 'repeat', in order to understand how it repeats itself and the potential implication of this phenomenon within weaving's notational system.

5.2 Case study (ii) — investigating the idea of the 'repeat' in weave structure notation

This second case study investigates the ways in which negative space repeats itself as part of a complete weave structure, i.e. a 'repeat'. It questions what the visualisation of a complete weave structure by means of negative space might uncover, and aims to question the binary model on which weaving is founded.

5.2.1 Repetition

In his theory of form, Bauhaus painter Paul Klee (1921-1931, in Porter Aichele, 1994) attests that repetition of horizontal and vertical lines is "the most primitive structural systems" (p. 84) (figure 5.4). Woven cloth is a matrix of perpendicular threads and its current structure notation is a linear grid. Thus, physically and pictorially, weave structure is the repetition of vertical and horizontal threads (cloth) and lines (notation).

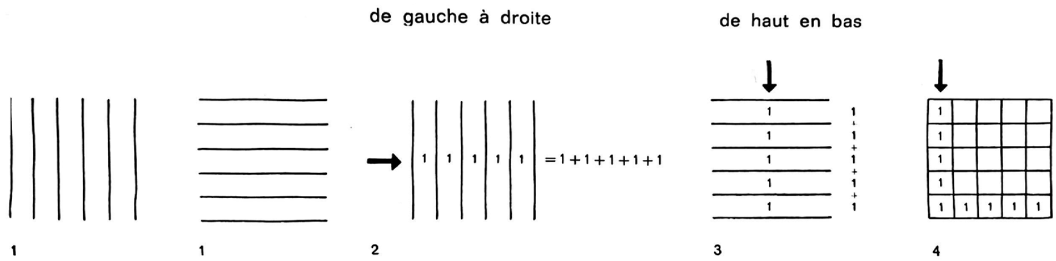


Figure 5.5
'La mise en forme structural. Structure (articulation dividuelle)
Paul Klee (1922, p. 217)

Repetition is defined as a methodical iteration of something that is already written or stated. It implies order, symmetry, hierarchy, stability, all parameters fundamental to weaving construction methodology. Ching and Francis (1979) explain that repetition is commonly understood as a grouping of visually similar things, spatially close to each other and arranged orderly. In line with Klee's thinking on structure, they state that "the simplest form of repetition, is a linear pattern of redundant elements" (p. 429), such as a square — a definition coherent to the modern weave structure notation. However, they specify that components do not need to be identical, but share commonalities so that, while belonging to the same group, they maintain individuality. Within a weave structure, each negative space isn't identical, but shares noticeable similarities with its neighbour (e.g. aesthetic quality of outline). This is particularly evident in sample O4 (image 5.37) in that at the microscale, negative spaces have alike characteristics (e.g. smooth edges, shape) but equally hold slight variations (e.g. outline trajectory, width). Although Ching and Francis write about architecture, their logic clearly applies to woven textiles. In fact, Albers (1957) points out that in comparing building and weaving processes, similarities of principles apply, regardless of scale. She mentions that both disciplines' structures are made of individual singular parts that form a whole matrix.

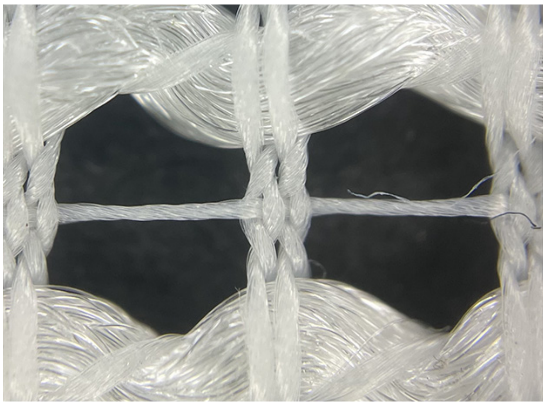


Image 5.37
Microscopy of sample O4's repeat
Ariane Fourquier (2023)

Urbanist Rasmusen (1959, quoted in Wolfe, 2014) explains that repetition is "the simplest method" (p. 01) for building a structured system, in that it imposes total regularity of components' formation. The current weave structure notation is indeed founded on 'total regularity', in that each square is identical in dimension and equates to threads' regular lift/drop action. Therefore, picturing weave structure through negative space poses questions as to the notion of strict repetition in weaving. Indeed, with regards to the previous case study (i), which evidenced the singularity of negative shape and the irregularity of its outlines, its repetition within a full weave structure might not portray identical features.

5.2.2 Ceaseless 'repeat'?

Recent research in mathematics has revealed the existence of a shape able to fill an infinite plane in a non-repetitive manner; that is, to produce a pattern that remains unique throughout (Smith et al., 2023). The shapes cannot be arranged together without being rotated or reflected (Sullivan, 2023). Yet together, the tiling of the shapes create an infinite pattern (figure 5.6, p. 95). A woven textile can only be constructed through the periodical repetition of its 'repeat', as it overcomes any visual and tactile disruptions within the cloth. In line with this parameter, the current notation of a 'repeat' is defined by a sequence of a specific square formation, whose edges must coincide for the creation of a seamless woven design. Depicting a weave structure 'repeat' with negative space therefore questions the idea of an unruptured pattern. At the study's scale, negative shapes cannot nest into each other, not only because their singularity obstructs the possibility of 'total regularity' in repetition but also because they are separated by yarns. This consolidates the argument made in case study (i) that using empty space alone might not be adequate for weave structure visualisation. Indeed, in comparison to the current notation, this would overlook an essential element of weave structure construction, i.e. yarns — an observation that requires evidence and reflection.

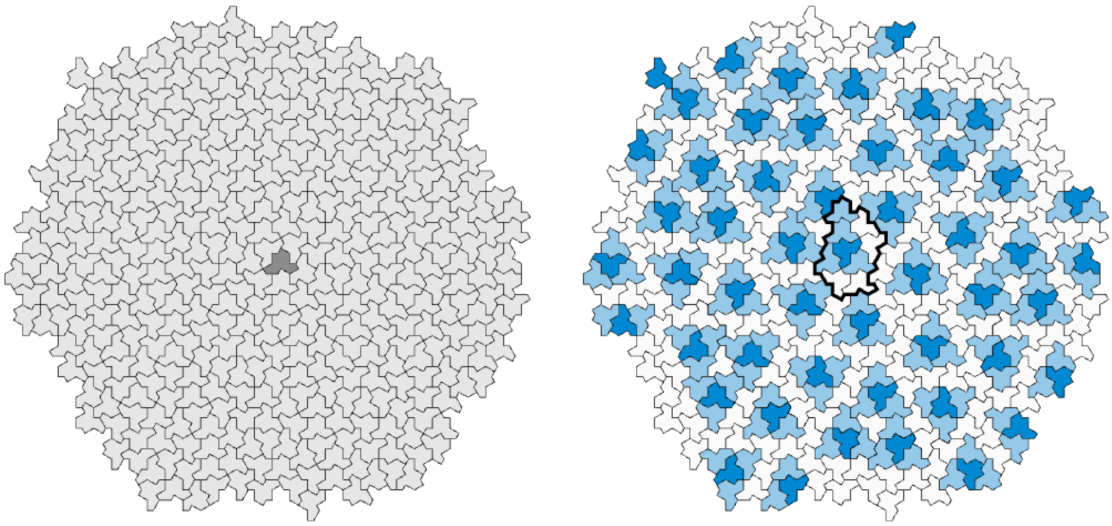


Figure 5.6
'A computer-generated10-patch of 391 hats, arranged in ten concentric ringsaround a central shaded hat'
from Smith, Myers, Kaplan and Goodman-Strauss (2024)

5.2.3 Discussion of the findings

Each sample within the 'squares' and 'triangles' groups, show four negative shapes in their 'repeat'. On the other hand, the 'other shapes' group pictures between four and sixty-four spaces, depending on the leno structure on which the sample was constructed. Throughout all samples, each 'structure unit' is different from its neighbour because of yarns' irregular nature. They differ in surface treatment, outline characteristics and size, which confirms their singularity. This is particularly relevant in sample O2 (image 5.38), which counts sixty-four negative shapes within a 'repeat'. While they present visible similarities (e.g. overall rectangularity, sharp edges

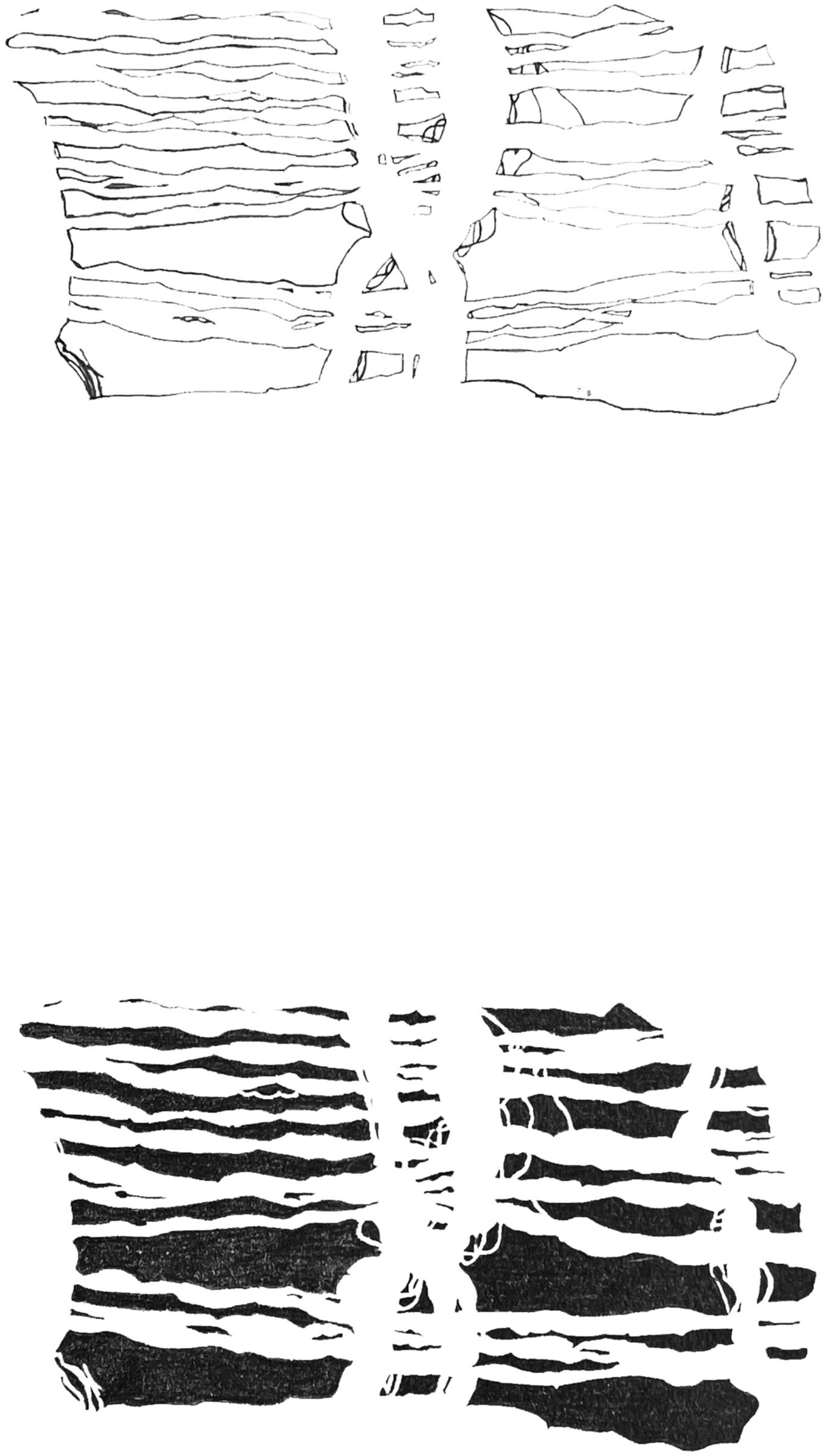


Image 5.38
Drawing of the 'repeat' - sample O5, pencil on paper
Ariane Fourquier (2023)

and minor thread overrunning), which picture a cohesive whole, each dramatically differs from the other in width and length. As such, this visualisation presents inaccurate repetition, in the sense that a pattern of alike negative shapes occurs but none are identical copies. As such the aforementioned 'total regularity' parameter of repetition isn't respected. Negative shapes' similar attributes nonetheless show the possibility of consistency in the structure of the forthcoming whole woven cloth, hence suggesting the hole's integration within the sequence.

Another consideration is that across all samples, the repetition of negative space depicts a grid-like sequence. As mentioned above (section 5.2.2), drawings visualise a matrix of broken up negative shapes, which evinces fluidity and disorder contrary to modern notation's rigidity and linearity. This is because of negative shapes' irregular outline and surface. It therefore signals a possible disruption between the fluidity of woven cloth and the inflexibility of the current notation. This tension is also illustrated in the paradox that weaving as a craft, art and design discipline embodies. In essence, albeit being governed by the orthogonal interlacement of linear yarns, its systematic construction methodology gives rise to a three-dimensional cloth that behaves in unruled ways. Thus, the visualisation of a weave structure 'repeat' through negative space illustrates that fundamental tension, that which defines the antithetical nature of weaving both as a framework of thought and creation. This observation points towards non-linear and organic ways of thinking and making which substantiate a holistic approach to weave structure visualisation, as opposed to a manufacture-focused one.

However, depicting weave structure through two distinct systems maintains weavings' polarity. In fact, both current and novel notational systems employ the same colours, i.e. black and white. This preserves the binary model on which weave structure notation is based. Nevertheless, what the colours signify is different. In the visualisation proposed, black refers to empty space as opposed to the lifting of threads and white relates to occupied space as opposed to a lowered/stationary yarn action. This difference identifies that a visualisation through negative space is not fit for the machine to function. It therefore corroborates that the alternative perspective the study takes facilitates moving beyond understanding weave structure notation as a mere manufacturing tool. Yet the sole use of black and white might not be adequate to portray empty and occupied space's interrelation and does not prove their possible synergy. Weaving's binary model is therefore not fully challenged.

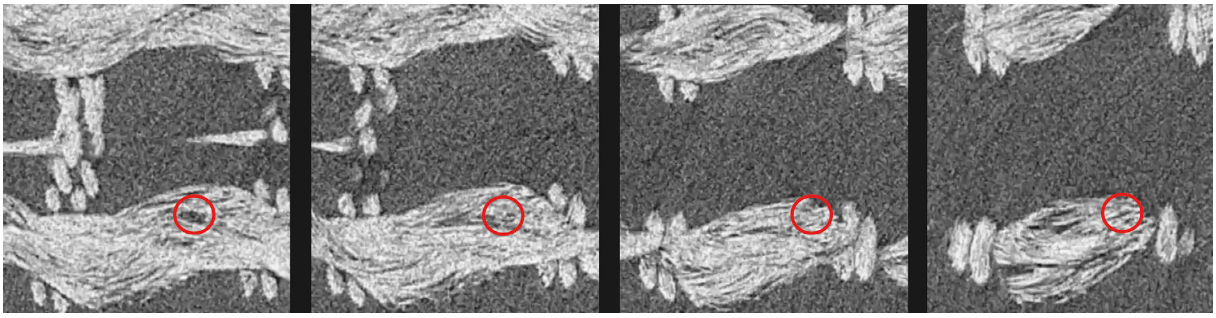


Image 5.39
Four consecutive X-Ray CT scan slices
Ariane Fourquier (2023)

Analysis of non-manipulated X-rays presented weave structures in a range of grey nuances. Within a chronological series of four X-Ray CT slices, one can observe drastic changes at the same location. Indeed, the size, shape and position of empty and/or occupied space shifts as the slices are animated (image 5.39). This confirms that the two systems exist in a symbiotic relationship and authenticates their interdependence and synergy as a holistic whole system. But how might one illustrate such a relationship?

The blurred aspect of X-Ray CT scans could pose issues in regards to accurately visualising a weave structure. However, X-Rays CT scans' hazy quality can be paralleled to the fuzziness of yarn's wooly tufts and the ways in which they occupy and thus sculpt negative shape. Likewise, indistinct shapes could serve as significant evidence that empty and occupied space are separate systems that coexist yet remain inseparable. The lack of visual sharpness and clear definition portray a gathering of elements that are seemingly part of a compound system. This is shown through tonality, which suggests that the colour grey might offer fruitful insights to evidence this synergy (chapter 06).

5.2.4 Conclusions

The two case studies have evidenced the following:

- As 'structure units', negative spaces present unique features (e.g. shape, size, borders' aesthetic quality) which manifests their singularity. However similarities can be identified, allowing classification into groups of alike characteristics, namely 'squares', 'triangles' and 'other shapes'. This duality was evidenced at the macro, micro and nano scales, which respectively enabled general categorisation, accuracy of negative spaces' unique features and reflection on its role in relation to the wider weave structure.

- Within a full weave structure, negative spaces repeat themselves in an irregular manner. They together form a sequence but lack accuracy in their repetition. In other words, no negative space is identical to its adjoint, yet within a repeat, makes a cohesive whole. As a result, a topology of disconnected holes is drawn, resembling a fluid and organic grid.

- The visualisation drawn in case studies (i) and (ii) uncovered that a notational system through negative space alone doesn't reflect the reality of weave structures, in that it overlooks the intrinsic presence of yarns. In effect, occupied space, i.e. threads must be considered in the development of an alternative notational system. Likewise, although black and white reveal insightful information regarding visual features of negative space, their sole use proved the new visualisation restrictive. The two colours maintain a binary approach to weave structure visualisation, in which negative space and yarns are separate systems. In these two case studies, binary, repeatability and uniformity of form is challenged, which implies that another way of notating weave structure might require not only the visualisation of empty and occupied space together, but also an embrace of the idea of tonality. In other words the realm of grey nuances might enable a move away from individualising elements that appears to be part of a whole system.

5.3 Reflections

The idea of negative space as a volume needed further exploration. While physically its lack of definite front and back sides hinder its pictorial representation through drawing in black and white, the digital space originally hinted towards other visual possibilities. Specifically, Rhino, a computer-aided 3D modeller for virtual graphic renderings, is an appropriate software for beginners to interact with drawing shapes in the digital space.

Sample S1's negative spaces were sketched on the software's x; y axis graph. Because of the pictorial complexity of negative space as a geometric shape, a continuous line couldn't be drawn. This means that where each outline changed direction, a new point was drawn, allowing each point to link and create segments, together forming a full shape (image 5.40, p. 101). To create 3D models, the software's extrusion tool enables extruding the shape along the z axis —

hence rendering a tridimensional volume. This tool can vertically expand the shape infinitely within the software's frame. Rhino permits a 360 panoramic view of negative space, allowing the shape to be explored from any direction and any perspective. Zooming in and out also permits an observation of the space from different dimensional perspectives. That is to say, either the shape resembles a black dot or one finds themselves able to examine the space from within it. When the extrusion occurs, the flat shape bottom face is duplicated, giving rise to its top equivalent; each point initially marked is copied. Among other modes of representation, including solid opaque shapes, transparent rendering reveals a 'see-through' 3D form. This is important to note because the points (bottom face) and their respective duplicates (top face) join into vertical segments; henceforth visualising striated 'sides' of the negative space (image 5.41). The thickness of the shape's extrusion is arbitrary, in that it is relative to the doer's decision. In architecture for instance, the extrusion is dependent on the shapes's desired height and can be mathematically calculated to digitally represent 'real life' prototypes. Here, a play between different random heights didn't reveal accurate data as to a visualisation of negative space as a 3D volume.

Limitations to using Rhino are myriad, including my limited knowledge and experience in the software's multiple tools. However, from a strictly observational view point, depending on the scale at which one manipulates the 3D model, the striated sides together visually appear in a range of blacks and whites, even though each are individual black lines. The more zoomed in, the more variety of shades appear. This is due to the segments' closeness (images 5.42 and 5.43). Equally, this visual appreciation could be interpreted as the fuzziness of yarns — pointing towards the inseparability of occupied and empty space in weave structure visualisation.

While offering interesting ideas, Rhino experiments were judged inconclusive because the observations were solely driven by the researcher's personal appreciation and interpretation of the 3D model. Yet, Rhino tests confirmed the potential importance of visualising negative space as a volume and hence picturing its depth on the digital sphere (chapter 10). More importantly, it confirmed the potentiality of tonality because, while each vertical segment is digitally black, the full render appears in a scale of grey nuances. Regardless of such limitations, studio practice thus continues to question: how does visualisation impact our understanding of the geometry of weave structure?

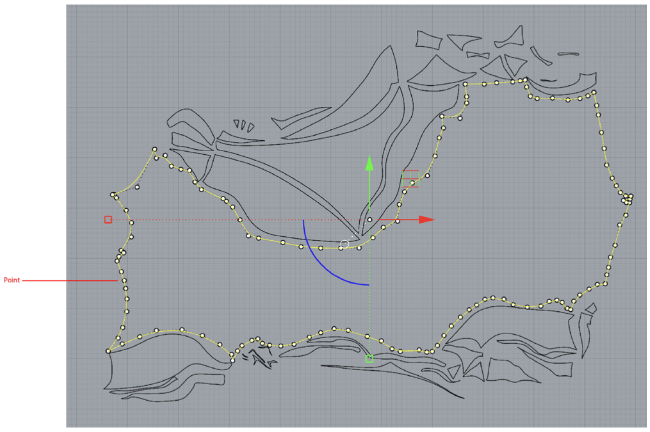


Image 5.40
Flat Rhino draft of sample S1 on x; y axis
Ariane Fourquier (2023)

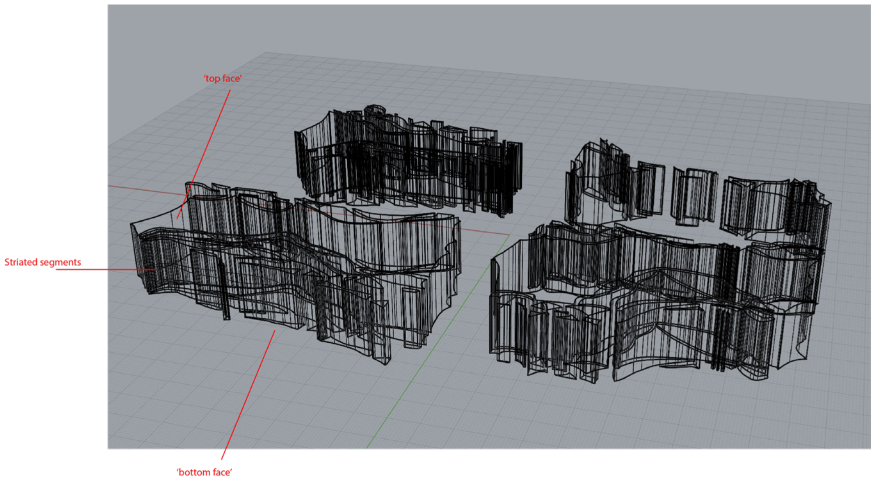


Image 5.41
Extruded negative spaces of the 'repeat' of sample S1
Ariane Fourquier (2023)

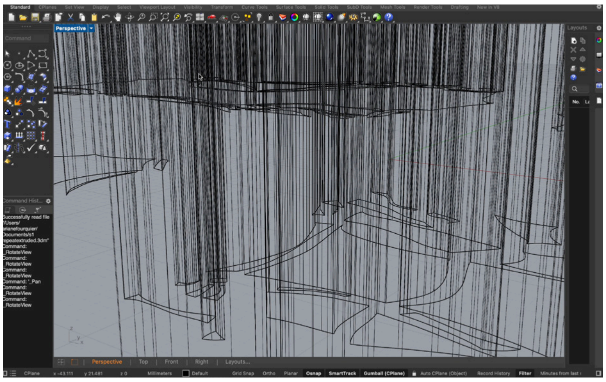


Image 5.42
Short extrusion of sample O1, side view
Ariane Fourquier (2023)

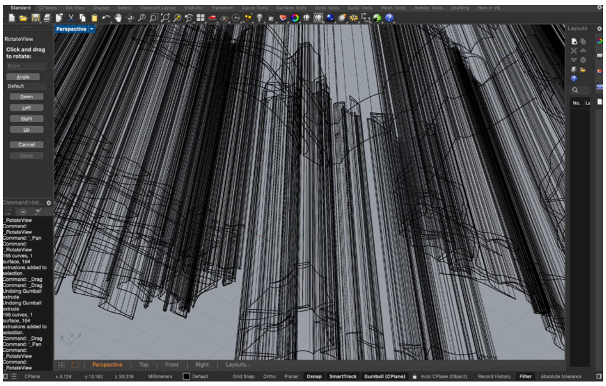


Image 5.43
Long extrusion of sample O1 bottom view
Ariane Fourquier (2023)

Nuance(s)

exploring empty space through tonality

06. Nuance(s) — exploring empty space through tonality

This chapter outlines the third case study and discusses its findings. It focuses on the idea that empty and occupied spaces should be visualised together in weave structure notation, and investigates what tonality can reveal about such a system. As weaving is founded on a binary model, the study was instigated by the question: can tonality break the boundary of the binary?

The black/white visualisation of case study (i) and (ii) showed limitations with regards to escaping the polarity model of the modern weave structure notation. As a result, tonality, here referring to the colour grey, proposes a boundless tonal chart ranging from light to dark. It was therefore judged suitable to examine the apparent interrelation between occupied and empty space noted in chapter 05. Research unfolded through experiments with the drawing technique of 'greying' (section 6.1.3), intertwined with a conceptual reflection on grey throughout the chapter. Equally to case studies (i) and (ii), it is experimental because an analysis of greys' characteristics within drawings, paralleled with X-rays CT scans' tonal quality, initiated the exploration of the colour's role in weave structure visualisation.

6.1 Exploring the use of grey to draw another weave structure visualisation

The fundamental difference within this experimental case study is that negative space refers not only to the 'structure unit' of case study (i) but also to the holes within yarns, those discernible at the microscopies' resolution (x200). By drawing in grey tones, i.e. 'greying', grey is considered not as a single, monochromatic colour but as a tonal one that embraces the infinite nuances it encompasses. Grey therefore facilitates a new way of exploring negative space within weave structure. As such, in order to step away from the constraint of the machine, the binary model on which the current notation system is based must be put into question. If grey can dismantle binarism, what does it mean for weave structure visualisation? What can be drawn from taking away this fundamental parameter in the visualisation of the craft's construction methodology?

6.1.1 Aims and objectives

This case study seeks to investigate another way of visualising weave structure, by simultaneously picturing both empty and occupied space. Aiming to step away from the polarity model of weaving manufacturing, it explores what an alternative way of drawing weave structure can uncover. The objectives are as follows:

(1) **Use 'greying' as a technique for visualising empty and occupied space** to draw weave structures.

(2) **Question the value of grey,** if any, as a way of visualising weave geometries and investigate what the idea of nuance can reveal in the interpretation of the new notational system.

(3) **Question what a break away from binary systems** in the visualisation of weave architectures might uncover within weaving as a textile construct.

6.1.2 Practical explorations

Weave structures were first sketched in grey, black and white, using the microscopies as a visual basis. As Berger (1960) writes, "drawing is discovery" (p. 1), inferring that the act of drawing and the decisions that come with it are led by the object of study. Thus, tracings were secondly conducted by solely imprinting grey-filled spaces in order to further explore the role of grey in weave structure visualisation. This enabled the study to deepen its reflection on the potential of grey, as initial observations of drawing suggested that the colour permits visualisation of occupied and empty space's connectivity. Designating the threshold at which grey shifts into black was aleatory and driven by intuitive interpretations based on a comparison of black areas' topology within a complete weave structure.

A selection of three samples per group, including those created by industrial means, permitted a focused analysis of different weave structures. Similarly to case studies (i) and (ii), industrial samples presented greater weave structure uniformity throughout the whole sample in comparison to hand-woven ones. This uniformity needed to be verified in relation to grey nuances. The remaining two samples within each group were chosen based on the properties of warp and weft, that is, a sample with evident holes and one with little to no apparent holes within yarns. Certain yarns (e.g. sample T2) present higher amounts of woolly tufts, potentially leading to drastic pictorial variations (image 6.1, p. 106). These parameters demanded consideration for greater accuracy of analysis. This is because, alike to negative space's complexity, grey's nebulosity could communicate inconsistency and unpredictability in the data, which, in conformity with data humanism analysis, must be acknowledged and validated (chapter 02).

6.1.3 Greying as a drawing technique

'Greying' as Gustafsson (2023) writes, is a technique that generates space, in that it does not focus on figures' edges but on their shared surfaces. In other words, greying allows a depiction in shapes as opposed to lines. The author also notes that greyness is "a medium in its own right" (p. 362). As such, 'greying' is not a simple method for depicting the object of study. Rather, drawing undeniably assumes the role of medium as a vehicle that communicates a surface's content (chapter 05, section 5.1.4). In the digital space, this is equally relevant because grey was first identified through the observation of non-manipulated X-Ray CT scans, which, within each slice, picture yarns and negative spaces in light-to-dark gradients. Once animated, the slices together visualise grey nuances merging into each other. Thus, within X-Ray CT scans, linear depiction does not occur. Instead, two systems appear to react to each other, one in lighter shades of grey, i.e. yarns, the other in darker tones, i.e. negative spaces. This points towards the questions: What is this reaction and how might one picture it?

Paul Klee begins his Creative Credo (1920) with "Art does not reproduce the visible but makes visible" ([no pagination]). He personifies the line, describing it as an active protagonist going "on a walk" (1925, p. 16) — extending its meaning beyond that of a mere representational tool. In this research, the pursuit of visualising through drawing 'unseen' spaces in weave structures is made possible by means of 'greying' a surface. That is to say, a succession of lines which together allow surface to be made visible, hence suggested by a progression of shades.

Furthering the reflection on lines, Merleau-Ponty (1961, quoted in Vellodi, 2023) argues that "there are no visible lines in themselves" (p. 308). This statement imparts that lines suggest, but do not outline, the visible and the invisible — evincing what will become space, be it occupied or empty. Greying is therefore established as an appropriate and efficient technique, because such a

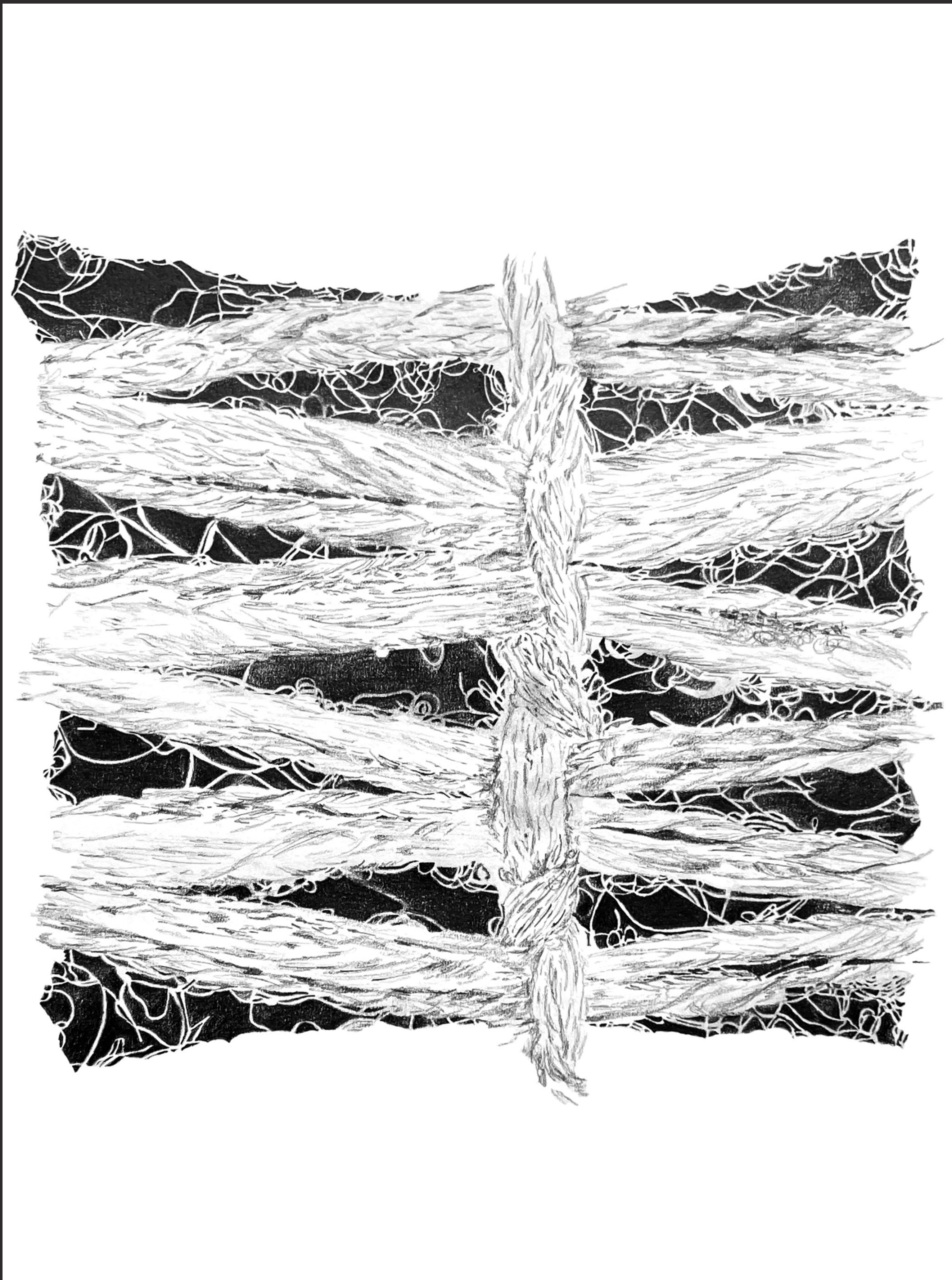


Image 6.1
Drawing of sample T5, pencil on paper
Ariane Fourquier (2024)

practice proposes that lines can never be understood individually. They are always dynamically reacting to each other. In effect, 'greying', embraces nuances and acts as a notational tool, granting empty space agency, as opposed to solely seeing it, and thus representing it as it is.

6.2 Discussion of the findings

The findings of the case study are discussed below in chronological order. First, initial grey drawings were analysed. The findings and their limitations were then interpreted in conjunction with insights inferred from grey tracings.

6.2.1 Grey drawings — understanding occupied and empty space's coexistence

Initial observations of drawings identified that light grey tones occupy warp and weft's empty spaces — darkening where leno and stationary warps cross. Darker greys visualised negative spaces in-between yarns — lightening in various areas, depending on the sample. For instance, sample O3 (image 6.2, p. 111) presents a dark-to-light gradient from one edge of the 'structure unit' to the other, softly transitioning into empty shapes within occupied space. On the other hand, the shading within 'structure units' in sample T1 (image 6.3, p. 112) is random and distinct, strictly ending at the shapes' borders; henceforth picturing a lack of empty space within yarns. This difference from one sample to another is due to the quality of the weft yarns specifically, i.e. aerated and loose in O3, tightly spun and dense in T1.

Across all samples, a separation between empty space and occupied space is clearly visible. This is due not only to the tonal scale, but also to the size of each type of surface. Additionally, 'structure units' are filled with grey in a continuous manner, while within yarns, grey surfaces are fractured. That is to say, certain areas remain non-drawn, representing the solid part of yarns. Whether empty space dissolves or directly shifts into occupied space, the notion of transition is interesting. Indeed, it suggests that grey can act as a bridge between empty and occupied space.

In his theory of pictorial configuration, Klee (1921-1931) gives grey a particular status by positioning it as the nucleus of the colour wheel. He advances that it is grey because it is simultaneously neither and both, black and white, up and down, as well as having no dimension but hovering in-between dimensions. As such, it is simultaneously a 'non-colour' and the source of all colours (Vellodi, 2023). In other words, it is a "mobile-equilibrium" (p. 301). This idea of mobility and balance is pertinent in relation to the grey drawings because it enables one to understand grey not as a representational tool but as an active element of weave structure visualisation. In effect, it gives ground for instability, unpredictability and fluidity — adjectives to which woven textiles's folding nature and in-flux behaviour cohere.

Klee's reflection stems from his notion of the 'grey point', that which, for him, is a primal "mathematical point" (Vellodi, 2023, p. 295), in the sense that it is a non-material, infinitesimal yet flat entity. The painter explains that in pictorial genesis, a shift from chaos to order enables the point to become perceptible and therefore grey; henceforth localising it "always in the middle of things" (p. 300). This consolidates the argument that grey's transiting characteristic enables the colour to act as a connecting tool between empty and occupied space; henceforth illustrating the synergy between the two systems while maintaining their distinction.

In simple terms, what Klee suggests is that, in pictorial configuration, nothing is ever grey and everything is always grey. Such an antithesis emerges in the visualisation of weave structures through grey. Within each sample, every 'structure unit' is unique in form and in the ways in which grey fills the shapes. While they present similarities — degree of gradient, fade direction or border's characteristics — each of them presents unrepeated characteristics. For instance, in sample S3 (image 6.4, p. 113), the 'structure units' are alike in regards to their wiry edges, the lighting-like ways warp yarns overrun the space and their overall shape that resemble elongated hexagons. Yet, the position of the hollow-like grey gradient or the direction and intensity of the wooly tufts differ from one negative shape to another. As a result, a checkerboard-like sequence of seemingly alike grey-filled negative shapes is identified.

This differentiation is also true of empty spaces within the yarns. Grey areas follow a specific direction, indicating a rough idea of the yarns' characteristics, e.g. twist, quality, property. Furthermore, grey fills occupied space in a greater range of shades, which, while evolving through lighter tones, brings depth, volume and a sense of movement. That is to say, as grey records the transition from occupied to empty space, it visualises the shift from one type of space to another. This characteristic can be compared to the aforementioned animated X-Ray CT scans, in which occupied and empty space blend into each other; henceforth confirming grey's ability to depict seemingly incompatible systems, which together form a holistic network.

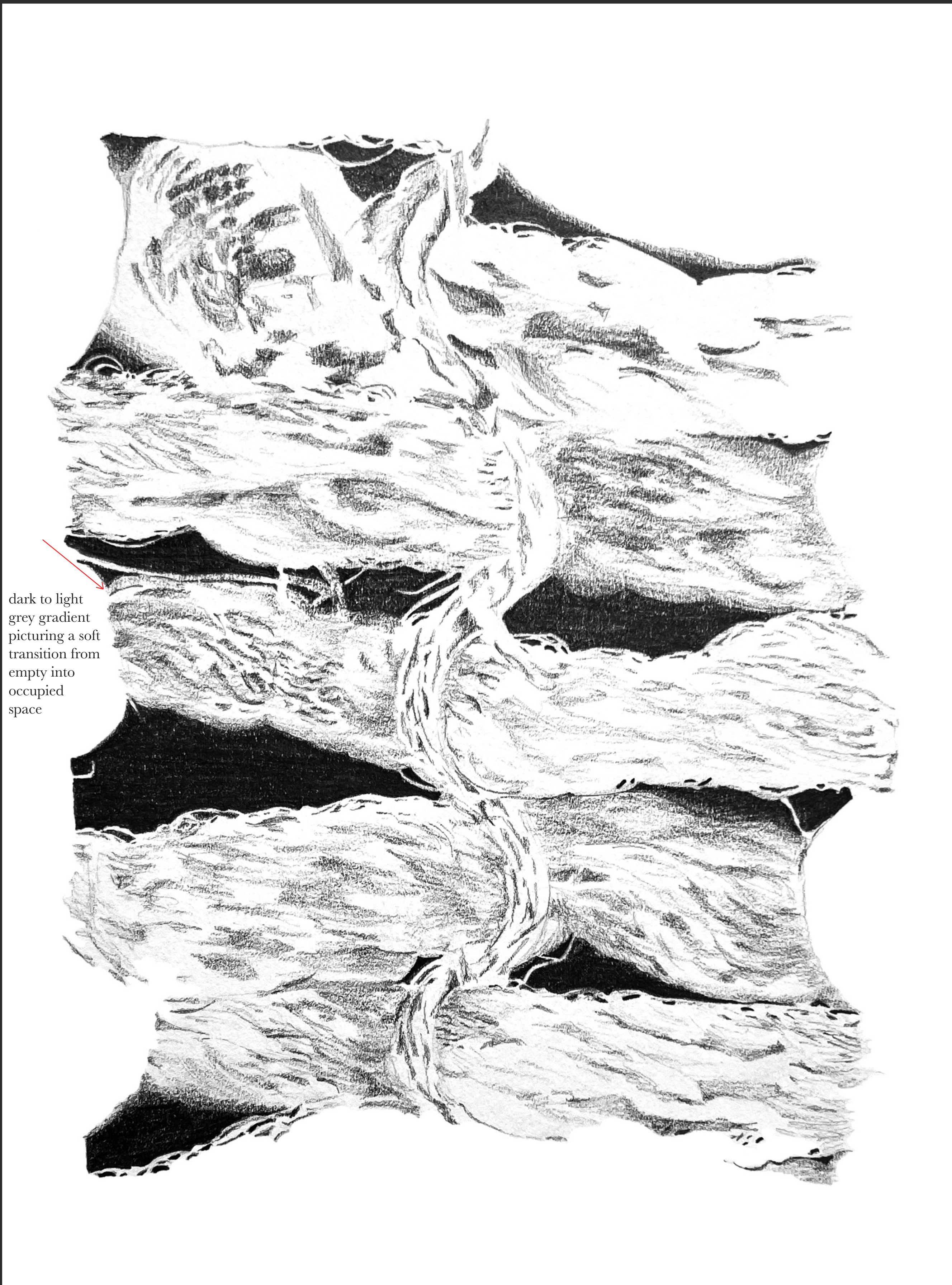


Image 6.2
Drawing of sample O3, pencil on paper
Ariane Fourquier (2024)

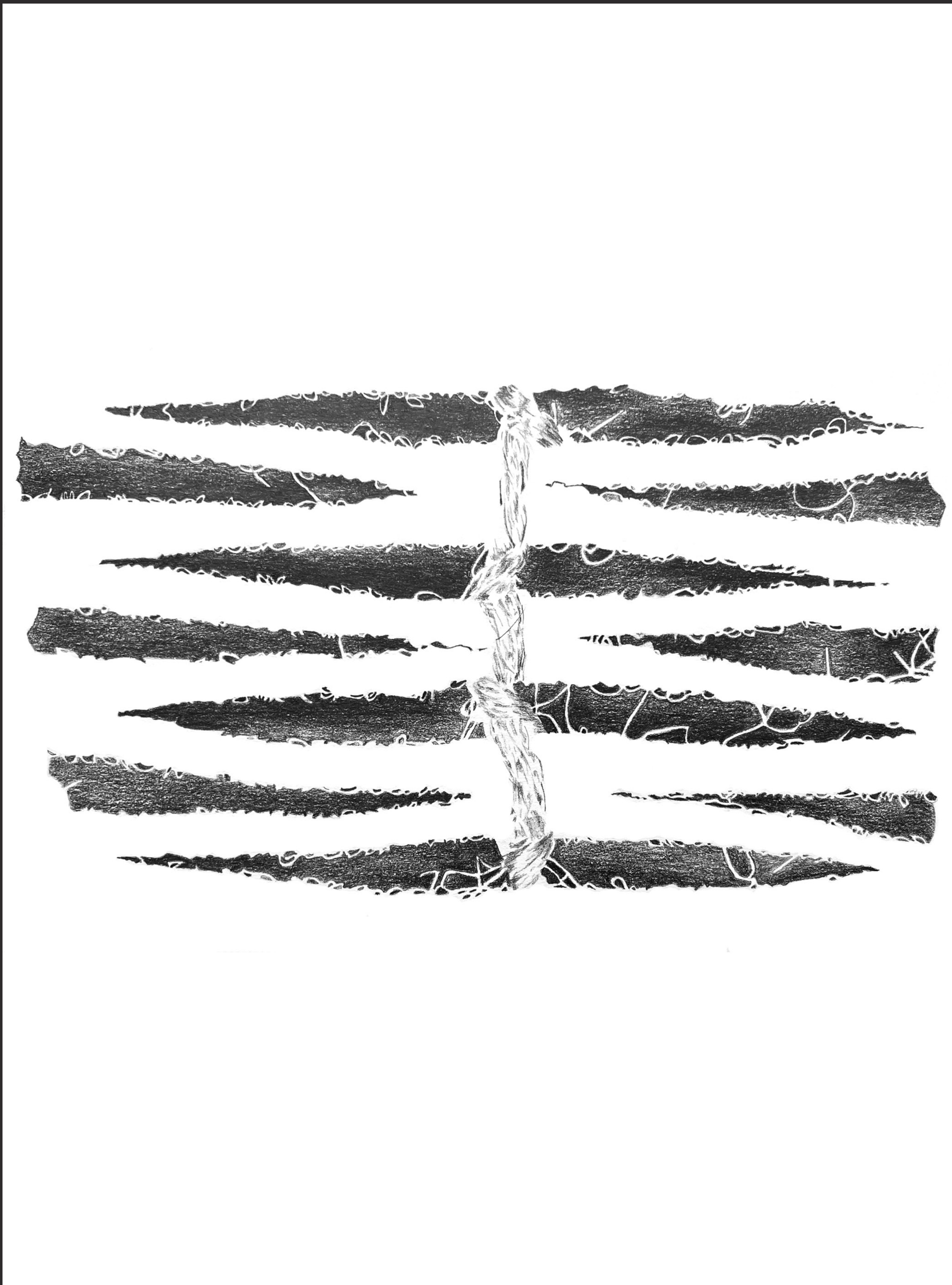


Image 6.3
Drawing of sample T1, pencil on paper
Ariane Fourquier (2024)

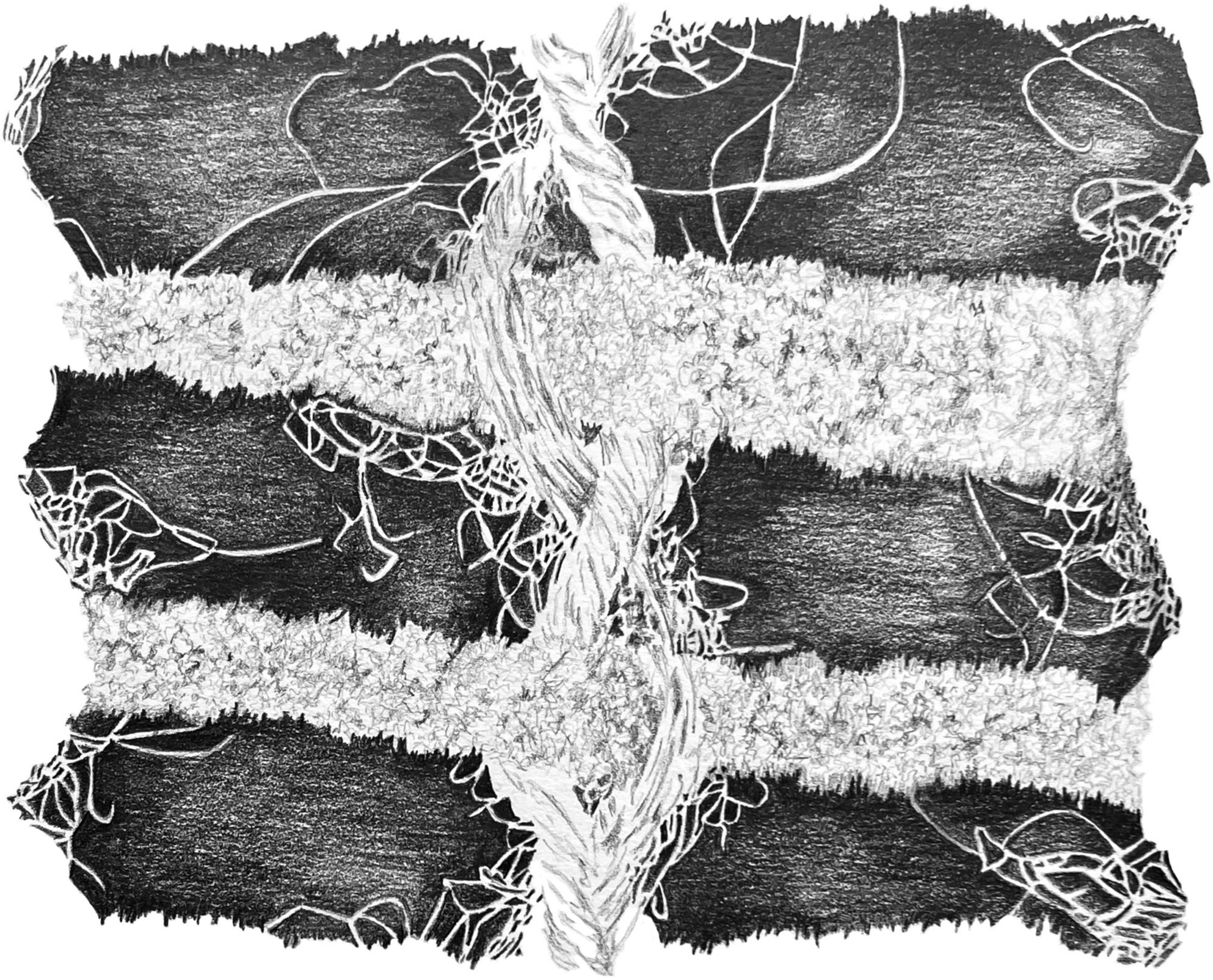


Image 6.4
Drawing of sample S3, pencil on paper
Ariane Fourquier (2024)

This apparent 'incompatibility' refers to the inherent difference of empty and occupied space as elements in opposite material condition and as distinct systems (chapter 05). The former is shaped by detached constituents which lack accurate repetition. The latter proposes an ordered and interlaced repetition of solid form. Yet, both form a fluid grid-like sequence individually and together.

Grey drawings thus depict a sense of instability, fluctuation, variability, which strangely appears to form an ordered and stable whole. Although the grey/black/white visualisation illustrates very well weave structure as a network of interconnected systems, can grey alone depict this symbiotic coexistence? And what can it generate?

6.2.2 Grey tracings — deciphering nebulosity

Tracings from grey drawings revealed new insights and new challenges. While they still aim to depict occupied and empty space, the composition resembles a cluster of ill-defined grey shapes as opposed to a clear weave structure (images 6.5, 6.6, 6.7, p. 116-118). Notably, tracings blur the passage from empty to occupied space, which makes it difficult to distinguish them as separate systems. This observation both limits and benefits the interpretation of visualising weave structure with grey.

Grey alone can only picture everything in-between black and white, thus rejecting the two poles, which dismantles any binarism. Although it might be relevant in regards to stepping away from the polarity model the current notational system follows, it also clouds the potential employability of the alternative visualisation. In effect, depicting weave structures with grey seems to reject the idea of both a binary or holistic symbolic system.

Chapter 04 and 05 showed that a weave structure is composed of two material elements in opposite conditions. Grey drawings validates and promotes this argument in identifying them as interconnected yet distinct systems. As mentioned, grey tracings do not visually allow this distinction. By this the research means that tracings' messiness seemingly exclude the presence of negative space, in that one cannot identify whether the so drawn negative space is the now traced empty or occupied space. However, the nebulosity that grey carries could equally be deciphered as further evidence of the systems' interdependence and harmony. Meaning that, a visualisation with grey alone fosters ambiguity, confusion, but could equally portray empty and occupied space's entanglement and symbiosis as part of a full weave structure. Although it is unclear to which system they belong, holes — represented through grey — are embedded into a wider w(hole).

6.3 Conclusion

This case study demonstrates that grey acts as an intermediary between two opposite systems, namely occupied and empty space — evidencing their coexistence, interdependence and synergy. Yet, the alternative perspective neither respects the binary model of modern notation nor does it completely dismantle it. This means that weave structure notation needs black and white to identify the two systems, intrinsic to cloth's structural stability. As a result, the presence of grey permits combining the two separate parts within a complete weave structure. Contrary to the current notation, which doesn't align with woven cloth's behaviour, a visualisation in grey nuances visualises the fluid and folding nature of woven cloth (chapter 08).

This chapter ends on open questions because, as a weaver and the sole agent conducting the research, my analysis of the practice limits the scope of interpretation. To me, drawings and tracings evidently visualise weave structures. However, how do others, i.e. non-weavers, understand and perceive this alternative notational system? I realised that the findings' analysis have thus far been restricted to my own technical and intuitive weaving knowledge. Therefore I organised an online seminar, inviting ten participants from various disciplines outside of weaving. This stage was crucial to deepen the meaning of grey in weave structure visualisation. Its unfolding and ensuing findings are exhibited in the next chapter (07).

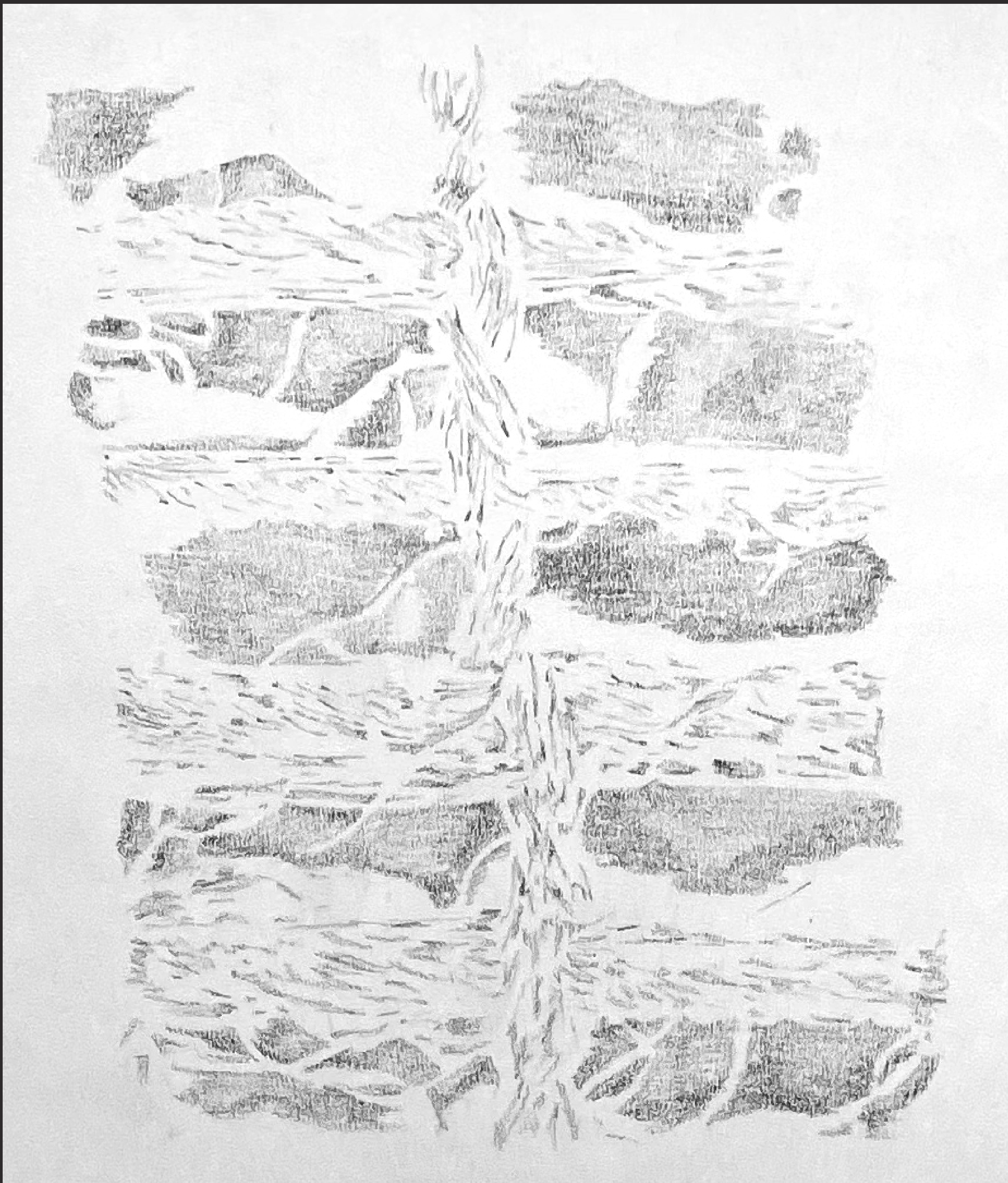


Image 6.5
Tracing of sample S5, pencil on paper
Ariane Fourquier (2024)

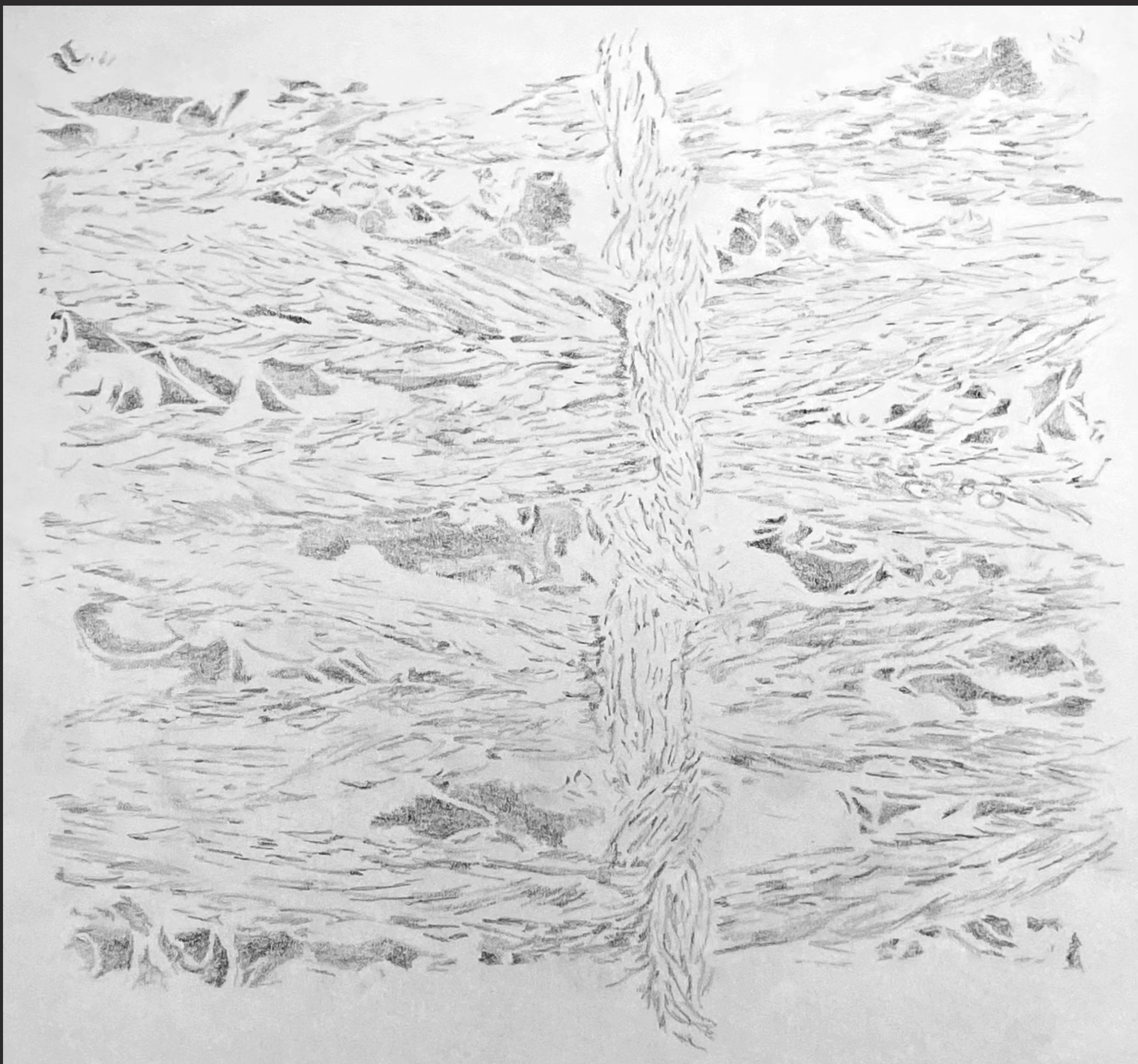


Image 6.6
Tracing of sample T4, pencil on paper
Ariane Fourquier (2024)

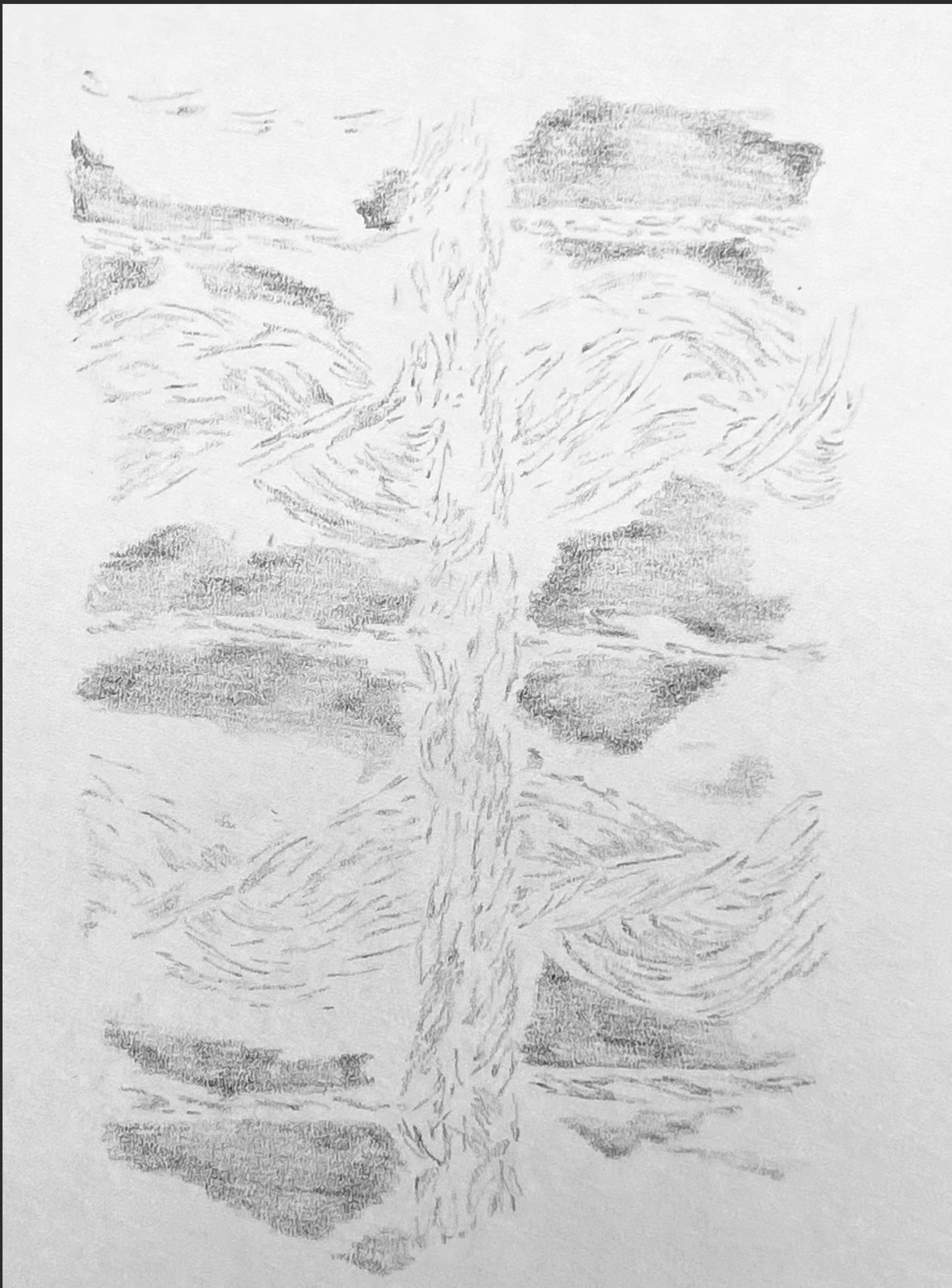


Image 6.7
Tracing of sample O4, pencil on paper
Ariane Fourquier (2024)

07. *CASE STUDY (iv)*

exploring the findings through others

07. Case study (iv) — Exploring the findings through others

This chapter presents the data drawn from a seminar organised after the completion of case study (iii). It is important to note that the analysis of the insights brought about several questions, which have been left unanswered in this chapter and are covered in the discussion of the thesis (chapter 08). This seminar aimed at testing the potential benefit of the new visualisation system, i.e. the drawings and tracings illustrated through grey tones, for practices outside of weaving and textiles. Here, the use of grey nuances needed to be tested: How do professionals outside of the discipline of weaving perceive and understand the alternative weave structure visualisation? And could this new symbolic system make the discipline of weaving more accessible to others?

A cohort of eight participants were individually contacted via email. Six were people I had interacted with during the early stages of this study, both within and outside my PhD cohort. The remaining two were found via attending a lecture series on regenerative design and through research into aperiodic tile geometry. All were selected because of their research practice, including art history, product design, design research, design thinking, material science, bio-design and geometric art. It is important to specify that the majority of attendees had little to no knowledge of weaving and cloth construction methodology, let alone weave structure notation. Only one participant was originally a weaver by training but had diverged from the discipline long ago.

After a brief presentation of the research, participants were asked to match grey drawings with the corresponding textile samples and pair grey tracings with the modern weave structure notation equivalent (images 7.1 and 7.2, p. 121). The first task was relatively successful, in that most participants correctly paired weave structure notation and woven textile. All attempts at the second exercise were unsuccessful. For the remainder of the seminar, participants were split into two groups and invited to engage in a discussion regarding the thesis' practice. The distribution of participants between groups was arbitrary, in the sense that their attribution to group A or B was not consciously done. To begin the conversation, some prompt were given, including,

- What did the visualisation make you think of, if anything?
- How does the proposed visialisation compare to the modern one?

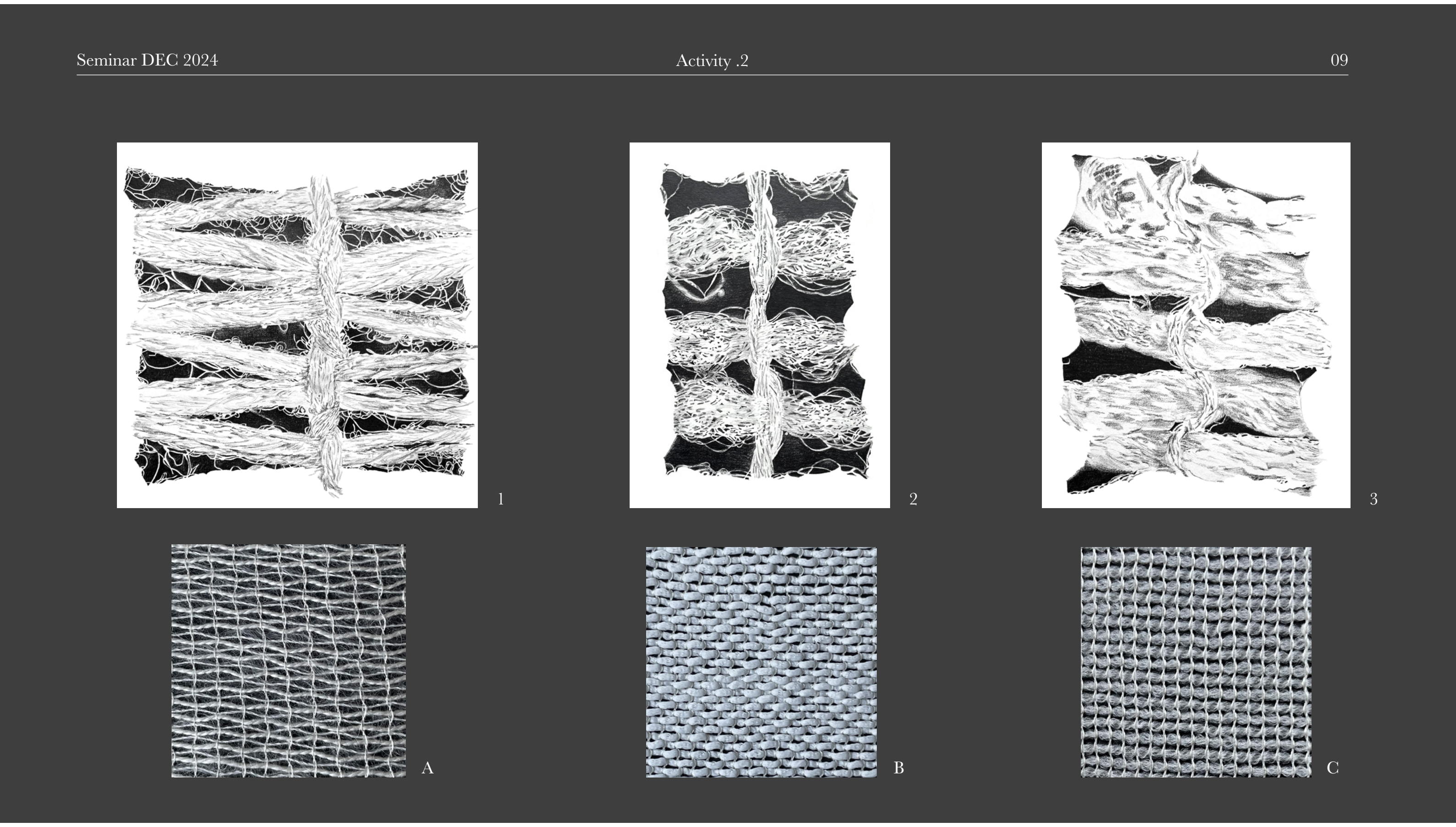


Image 7.1
Seminar slide, matching grey drawings with correct woven sample
Ariane Fourquier (2024)

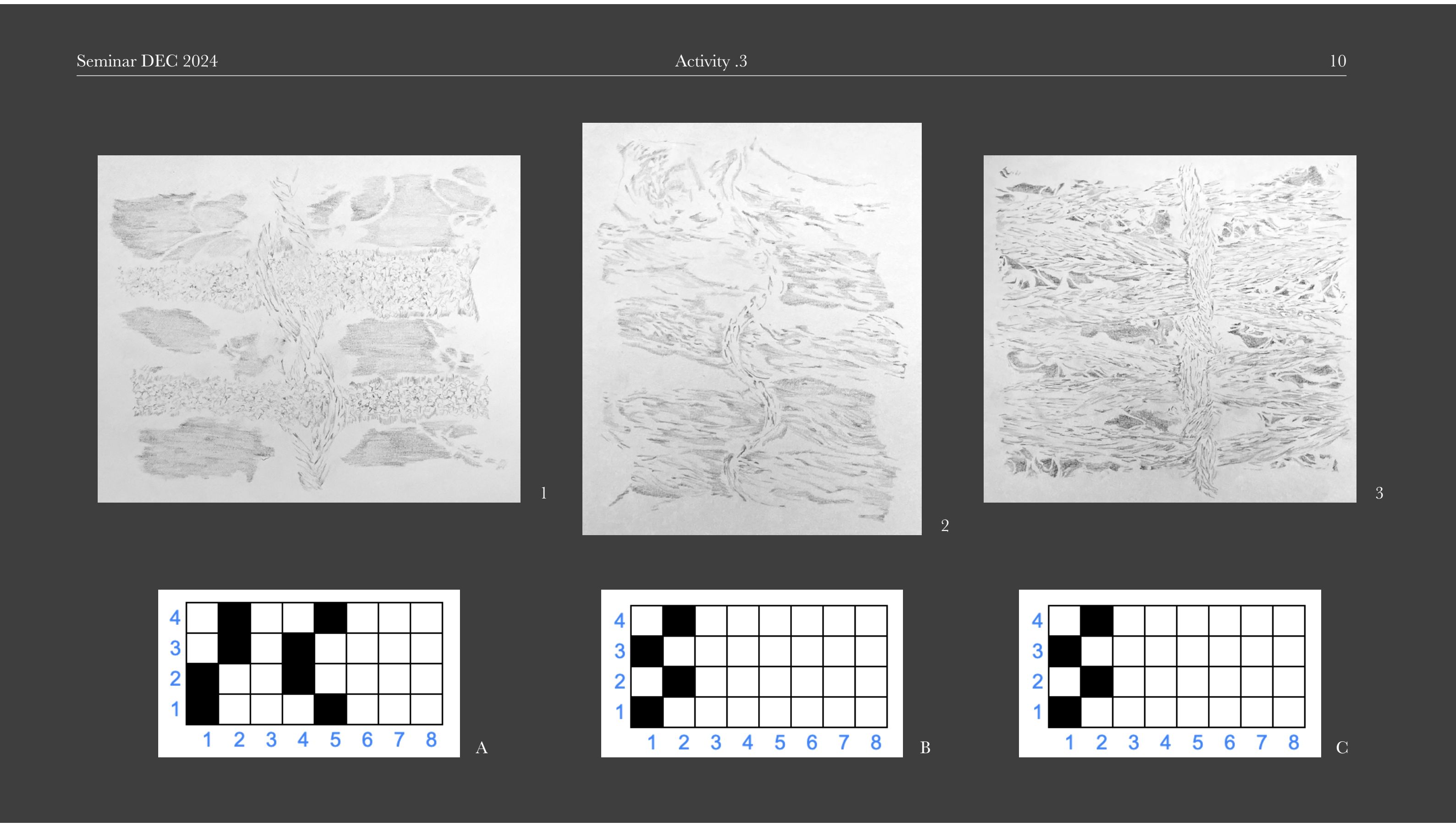


Image 7.2
Seminar slide, matching grey tracings with correct weave structure notation
Ariane Fourquier (2024)

- What are your thoughts regarding the use of grey?
- Do you believe black and white should still figure in the alternative visualisation system?
- Could this way of understanding weave structure notation have an impact on your own practice and /or research? If so, how?

Group A was composed of an art historian expert on Paul Klee and his work with weavers of the Bauhaus (participant A1). The second researcher's work involves non-destructive methods of analysing composite material behaviours (participant A2). The third person is a self-proclaimed "shape player" whose practice involves creating geometric tiles and pattern creation through Alpha numerics and cellular automata (participant A3). By 'playing' with shapes, they discovered the aperiodic 'einstein' tile, aforementioned in chapter 05 (section 5.2.2). Finally the fourth participant, also group facilitator, is a design researcher specialised in heritage engagement methods within the Nigerian Igbo culture context for product design processes (participant A4).

Group B comprised the above-cited formerly trained weaver currently investigating multispecies epistemologies, aiming to develop frameworks based on non-human knowledge (participant B1). The second attendee's research concentrates on wool ecosystems, addressing them using the concept of affordance (participant B2). The third researcher is a designer who practically explores ways of materialising dust and air pollution, i.e. visualising invisible material 'things' (participant B3). Lastly, the fourth participant is specialised in design thinking and works towards decentering humans from design making processes (participant B4).

During the seminar I positioned myself as a listener, as opposed to an active protagonist of the conversation. This is because I needed to understand how others perceive the proposed visualisation system, in order to test its validity and limitations beyond my own interpretations. However, the conversation that emerged from each cohort was drastically different. Group A's discussion concentrated on the practicality of the alternative weave structure visualisation and its limitations. Group B's considerations were conceptual, specifically reflecting on the value and validity of greyness in visualisation within this research and beyond.

7.1 The role of colour

Upon seeing the grey illustrations, group A instantly rejected the idea of a weave structure notation through grey. All participants agreed that such a visualisation is not clear and overly complex to understand, insofar that, had they been unaware of the research topic, recognising weave structure would have been impossible. Through a comparison of grey drawings and tracings, they inferred that contrast, i.e. black and white, was needed to distinguish empty from occupied space. However, their thought process wasn't made in relation to whether the notation could fit machine specification. Instead, it was solely driven by the pictorial configurations of the drawings and tracings presented.

Additionally, participants considered that, if the holes in-between yarns are pictured, warp and weft should also be identified. That is to say, occupied space shouldn't be depicted through the negative spaces within yarns alone. Not only does solid space need illustrating, but warp and weft should be differentiated. They suggested that using three colours would solve this issue. For instance, black for holes, white for warp yarns and red for weft yarns. Participants' reasoning followed the idea that all components should have equal value within weave structure visualisation. This input visually sets apart empty from occupied space and warp from weft — questioning the core inquiry of this thesis, that is, visualising weave structure as a holistic system. If negative spaces, warp and weft are colour-coded, how might the relationship between empty and occupied space be visualised? As mentioned in chapter 05 (section 5.1.4.1) colour was judged distracting in regards to depicting weave structure — an argument with which group B agreed. Nevertheless, the complete removal of grey could have value in regards to balancing hierarchy within weave structure. That is to say, could assigning a colour to warp, weft and negative space equalise their individual function? Group A's rejection of grey therefore induces a reflection as to a possible future visualisation of weave structure.

Conversely, group B interpreted grey as a colour that communicates the hole as a 'space of possibilities'. Although conceptually more in line with case study (iii)'s analysis, this idea raises questions: What does it mean for empty space to hold possibilities and what kind of possibilities does it allude to? Confirming the research's analysis of grey drawings and tracings, for them, greyness enables empty and occupied space to come together. It visualises their interconnectedness, allowing the opposite spaces to become one, that is, evenly part of a whole.

Such opposite approaches towards colour, and specifically grey, were fascinating. Are these divergent views related to one's research background? Indeed participants within both groups were tied by their approach to their own discipline. That is to say, in group A, participants' work relates to concrete objects and practical methods of making and knowing while group B mainly focuses on a more-than-human approach to design and materials. Nonetheless, these two viewpoints provided valuable insights as to contextualising the alternative weave structure visualisation and weighing its worth within the wider research landscape, i.e. beyond weaving.

7.2 Tool — "where not to weave"

Group A's confusion towards the colour grey compelled them to question the potential use of the alternative visualisation. Notably, they agree that it does not indicate clear enough data for woven cloth creation. Meaning that, unlike modern weave structure notation, it cannot communicate to neither machine nor non-weavers the woven textile's engineering principles, i.e. technical data for yarn assembly. However, in spite of the issue grey as a colour causes, participants found that grey is relevant for identifying empty space location within a weave structure. They concluded that it could be useful for recording weave structures or analysing woven textiles that have already been produced. Here the alternative weave structure visualisation is both a post-weaving communication and reading apparatus. Meaning that it isn't intended for the weaver to weave but it can be used as a tool for analysis. Participant A2, who employs X-Ray CT scanning in their research, suggested that the alternative weave structure visualisation could be useful to test the stability of materials. In other words, such an analytical tool could be efficient for estimating the quality of a material's structure before it has gone through extensive turmoil from external forces (e.g. weakening of a structure over time). This would be applicable to research in weaving and other creative disciplines within textile and beyond.

7.3 Non-written notation

Referring to the idea of communication, participant A4 raised the idea of oral knowledge and asked whether notation, and here weave structure notation, requires being written in order to communicate its message. They underpinned their argument with the example of the Kente cloth from the people of Ghana, whose making process involves singing. They wondered whether such a song served weavers to maintain weaving momentum or if sound pitch indicated the ways in which warp yarns lift. Such ponderings question the history of notation, the preservation of heritage in the face of the post-industrial and post-digital age and the significance of accessibility (e.g. non-sighted individuals). However, albeit fascinating, this reflection belongs to another research (chapter 10).

Nevertheless, the reflection on weaving knowledge communication challenged the function of the grey visualisation system. Having only been presented with the research's practice, with no theoretical context, group A struggled to see the purpose of this alternative way of notating weave structure. What is the incentive for drawing notation apart from industrial purposes? While the example of Kente cloth can be tied back to the importance of craft weaving methods as a transferable form of knowledge (chapter 08, section 8.6), group A's discussion clearly showed that the need to understand weaving away from the mechanical was difficult to grasp.

7.4 More-than-human — "beyond"

For group B, a visualisation of weave structure notation in grey identifies the hole as reacting to its surroundings. Participant B3 remarked that the hole "shapes itself with agency by filling in the grey zone". They argued that the modern black/white weave structure notation is human-centred, in that it presents an industrial perspective on notation. By stepping away from the mechanical, grey allows the hole to become its own agent. In other words, the colour portrays empty space as an active element of the whole weave structure. To simplify, participant B3 suggested that grey does not shape negative space. Rather, the hole uses grey as a medium to convey specific data, be it its location within weave structure or the content of its surface.

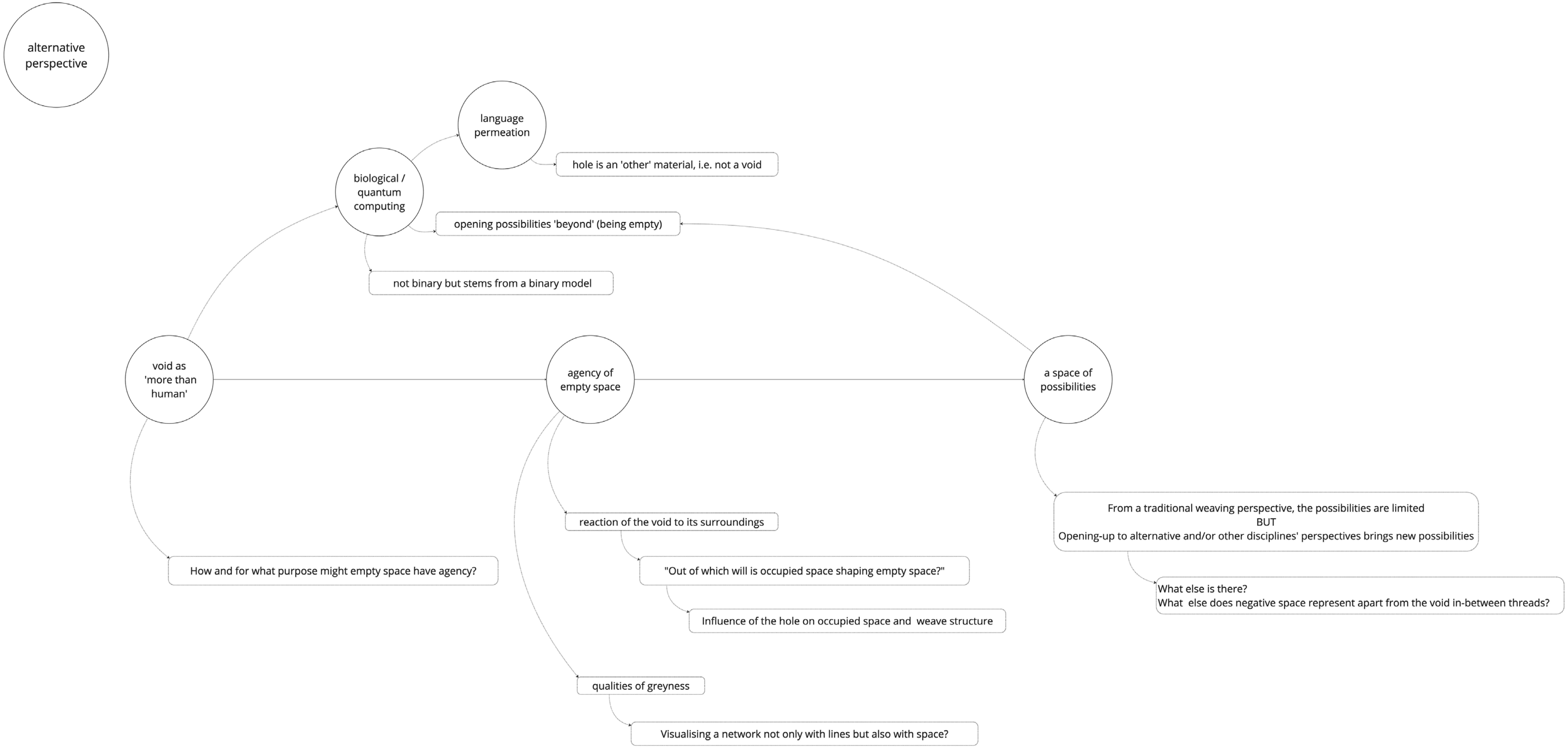
Building on this idea, Participant B1 recalled a recent exchange with researchers from the Unconventional Computing Lab (Bristol, UK) regarding microbial forms of interaction. They explained that biochemists are currently unable to understand why certain proteinoids behave in a specific way when replicating themselves. The participant noted that, interestingly, the data visualising the molecules' behaviour was in greyscale. They then suggested that this study's alternative perspective on weave structure visualisation could be a relevant tool, meaning that it could be useful for data analysis of greyscale imaging. In other words, weave structure visualisation in grey nuances could be used as a method for analysis. Additionally, the participant pointed out that, albeit stemming from weaving's 'traditional' binary principles, it is a non-binary perspective on weave structure visualisation. Thus in the context of biological computing, which doesn't function on binary code, this way of notating weave structure could provide a compelling outlook (chapter 10).

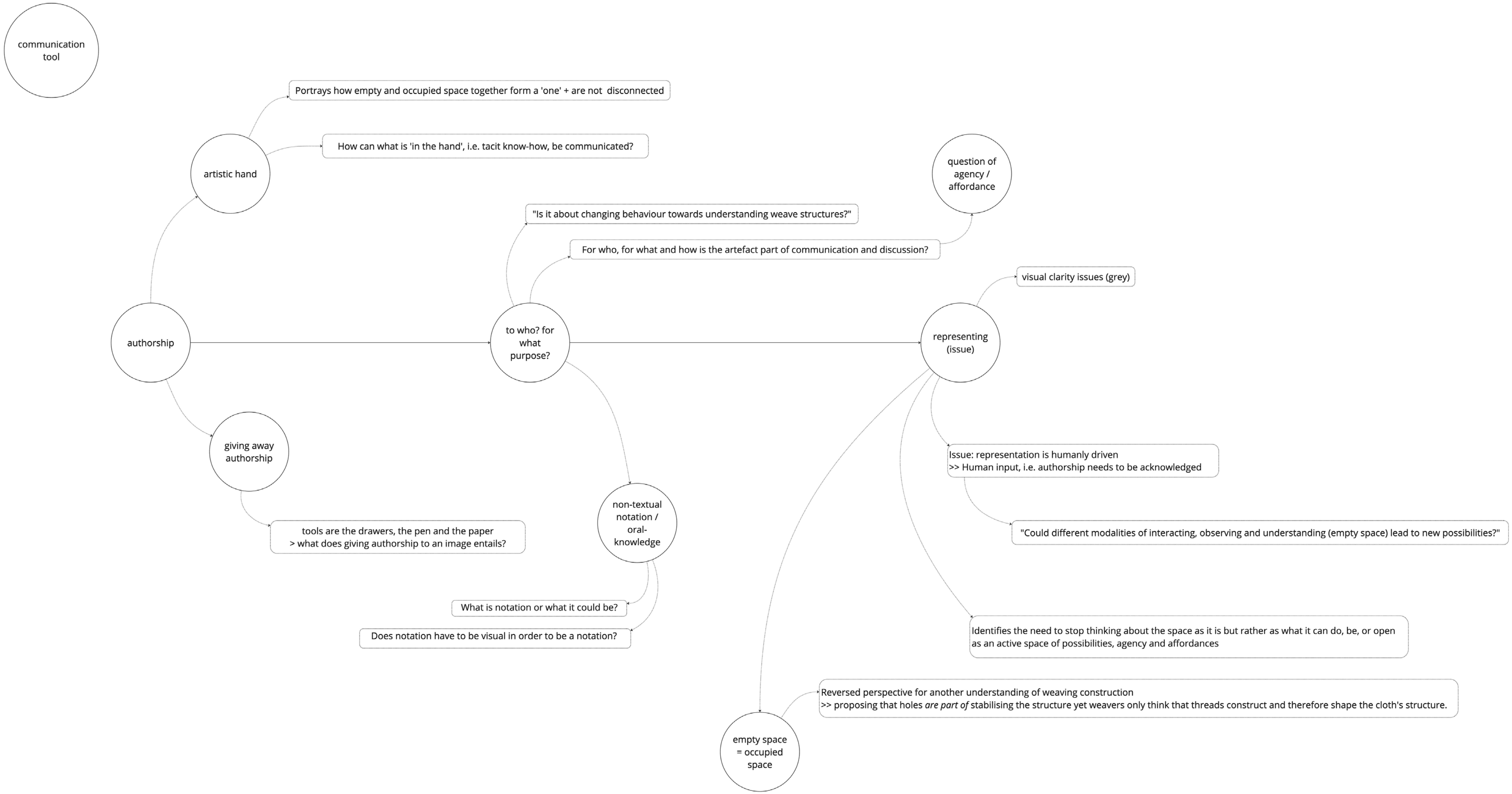
Adding to the debate, participant B4 explained that positioning computing into a "non-binary paradigm" that operates with more-than-human entities, enables alternative approaches. They inferred that negative space as an agential space could open possibilities "beyond". While this is a captivating insight, what does 'beyond' genuinely refer to?

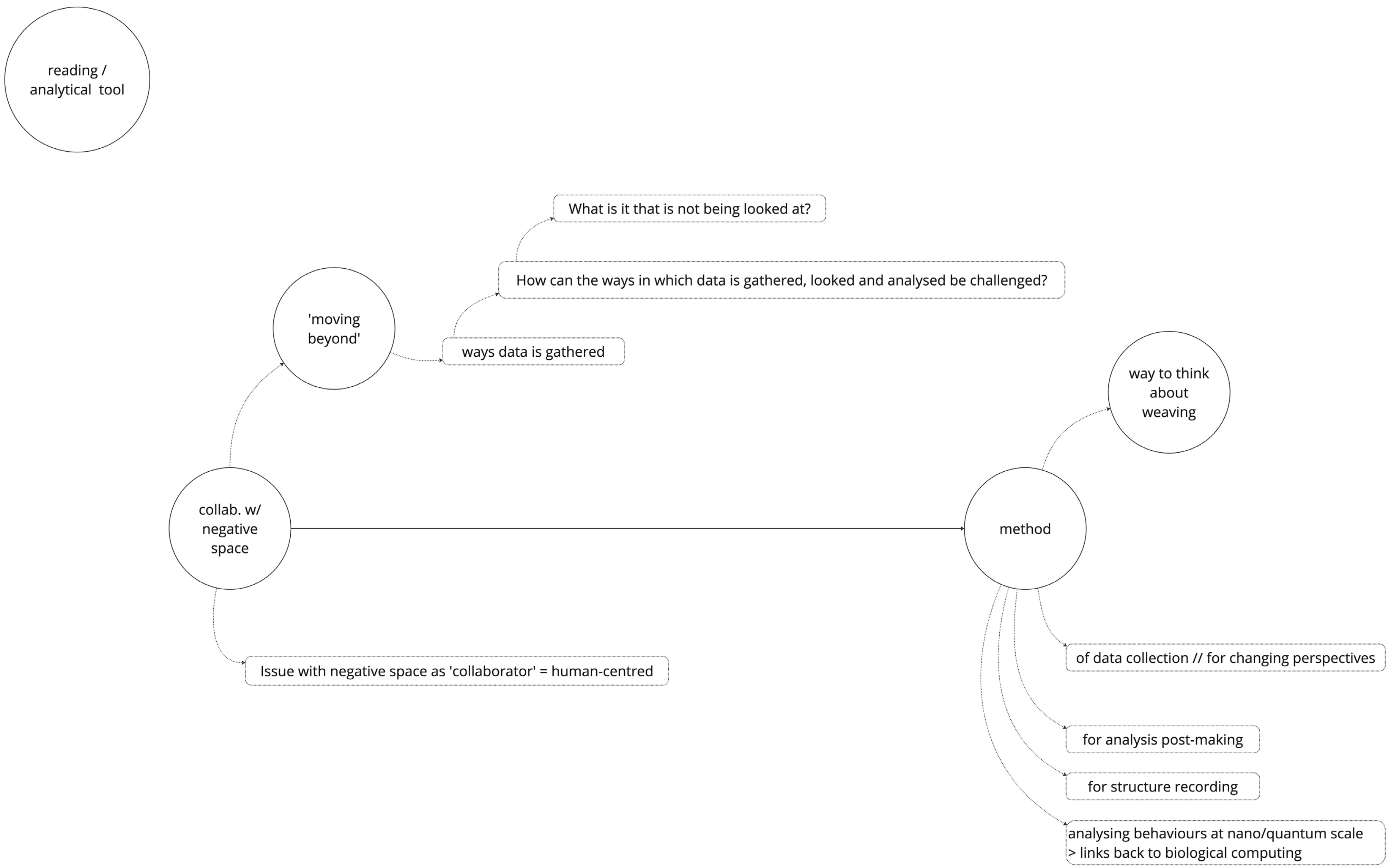
Participant B1 furthered this idea by connecting it to the ways in which data is looked at and gathered. They explained that, heavily relying on sight because of their tools (e.g. recording device, notebook), the ethnographer is always aware of the perspective from which they observe the object of study. The participant added that grey drawings afford a different mode of investigation, and signals what the researcher is not looking at. Returning to the idea of agency, participant B3 highlighted that this alternative weave structure visualisation differs from the industrial one because it represents the knowledge embodied by weavers' hands and body. This angle led participants to consider the notion of representation and the issues it engenders, because it is essentially a humanly-driven action. Yet if the artefact — here, negative space — has agency, how can such a quality be visualised and communicated? Participants therefore suggested that visualising weave structure through grey enables looking at empty space as a dynamic space of possibilities, that is to say exploring its capabilities as opposed to observing it as an entity. A holistic perspective proposes that negative space's function manifests itself in its relationship with neighbouring yarns and with the complete weave structure. Yet another form of interaction occurs, that is the one within negative space itself and hence outside of weave structure, which brings into question the boundaries of negative space already evoked in chapter 05 (section 5.1.5). Additionally, the possible influence of the environment in which a woven cloth 'exists' and behaves, and hence the role of negative space, are further questioned (chapter 10).

7.5 Reflections

The seminar revealed unexpected insights. Although group A's opinion confirmed the nebulosity of grey, it exhibited the impossibility for some other professionals to recognise weave structures in the drawings — inducing a disinclination towards the use of the colour. The drastic difference of conversation between group A and B was perplexing. On the one hand, group A voiced out their inability to understand the purpose of the visualisation beyond mechanical prospects. On the other hand, group B's discussion was more speculative and participants could discern the possibilities of exploring weave structure depiction through grey nuances and the potential benefits of such a study beyond the weaving realm. In effect, their interpretation was in line with the research's examination presented in case study (iii) (chapter 06). This split in opinion confirmed the value and future scope of grey in the visualisation of weave structure but equally advanced its limitation.


alternative perspective
language permeation
hole is an 'other' material, i.e. not a void
biological / quantum computing
opening possibilities 'beyond' (being empty)
not binary but stems from a binary model
void as 'more than human'
agency of empty space
a space of possibilities
reaction of the void to its surroundings
"Out of which will is occupied space shaping empty space?"
Influence of the hole on occupied space and weave structure
How and for what purpose might empty space have agency?
From a traditional weaving perspective, the possibilities are limited
BUT
Opening-up to alternative and/or other disciplines' perspectives brings new possibilities
What else is there?
What else does negative space represent apart from the void in-between threads?
qualities of greyness
Visualising a network not only with lines but also with space?


communication tool
Portrays how empty and occupied space together form a 'one' + are not disconnected
How can what is 'in the hand', i.e. tacit know-how, be communicated?
artistic hand
question of agency / affordance
"Is it about changing behaviour towards understanding weave structures?"
For who, for what and how is the artefact part of communication and discussion?
visual clarity issues (grey)
authorship
to who? for what purpose?
representing (issue)
giving away authorship
Issue: representation is humanly driven
>> Human input, i.e. authorship needs to be acknowledged
tools are the drawers, the pen and the paper
> what does giving authorship to an image entails?
non-textual notation / oral-knowledge
"Could different modalities of interacting, observing and understanding (empty space) lead to new possibilities?"
What is notation or what it could be?
Does notation have to be visual in order to be a notation?
Identifies the need to stop thinking about the space as it is but rather as what it can do, be, or open as an active space of possibilities, agency and affordances
Reversed perspective for another understanding of weaving construction
>> proposing that holes *are part of* stabilising the structure yet weavers only think that threads construct and therefore shape the cloth's structure.
empty space = occupied space


reading / analytical tool
What is it that is not being looked at?
How can the ways in which data is gathered, looked and analysed be challenged?
'moving beyond'
ways data is gathered
way to think about weaving
collab. w/ negative space
method
of data collection // for changing perspectives
Issue with negative space as 'collaborator' = human-centred
for analysis post-making
for structure recording
analysing behaviours at nano/quantum scale
> links back to biological computing

08.

Discussion

W(hole):
An alternative approach to weave structure visualisation

08 Discussion

At the heart of this research is the notion of 'w(hole)' and what it has revealed about weave structures and their visualisation. In simple terms, practically and conceptually, a pictorial investigation of 'hole' shuttled the thesis towards an alternative understanding of weave structure as a complex whole — one in which all material elements are intrinsic to the existence and functioning of a woven matrix. This holistic perspective stemmed from the idea that, as part of a network of multiple intelligences, including emotional intelligence, it is their interconnectedness and as a result, their mutual relationship to the whole system, i.e. the brain, that enables it to perform effectively. What led to such an approach and the insights that emerged from it are explained and discussed in this chapter.

8.1 W(hole)

It is important to state that the following reflection was made solely from an English vocabulary viewpoint. Alphabetically, the terms 'whole' and 'hole', are perplexing. How can the addition or subtraction of one letter, i.e. 'w', permute a word into its opposite? 'Whole' roots back to the Proto-Indo-European (PIE) *hal*, meaning 'entire, uninjured' — here referring to a whole woven cloth, that is, an entire surface. Reversely, 'hole' stems from the PIE *hol*, 'orifice, perforation' — here relating to empty space.

Orthographically, it is as if 'hole' becomes part of an entire thing to create 'whole', and is simultaneously absorbed by it. Meaning that 'hole' perforates the 'uninjured' and 'whole' integrates the 'orifice' (Fourquier, 2024). Such a paradox is rather bewildering yet is coherent in regards to woven cloth as material surfaces, in that it confirms that the woven hole (negative space) is part and a part of the whole (textile surface).

The idea of adopting a holistic perspective on visualising weave structure was driven by this impression of synergy between seemingly antagonistic components of a woven matrix; the thesis apprehends the hole as a constitutive element of a whole weave structure because of its relationship to the whole. The questions now driving this discussion chapter are:

> What is the nature of this relationship? What has it uncovered about the ways in which weave structure visualisation, and as a result weaving, is understood within and beyond the craft? And to what end?

8.2 Borders — characterising and identifying negative space within weave structure

The research question setting forth this study had to do with the potential role and value of negative space. Before any practical experiments were undertaken, negative space was thought to be an inherent element of a woven textile construct, as it seemingly allows threads to form the orthogonal matrix. As stated in chapter 01, without holes, woven cloth would be an aggregate of loose vertical warp ends and horizontal weft picks. Case studies (i) and (ii) (chapter 05) respectively investigated negative space as a 'structure unit' and through the 'repeat'. The aim of these early explorations was to observe and characterise negative space and identify its location within a woven matrix. As per the discussion in case study (i), observations at the macro scale of woven samples identified negative space as an entity in its own right with distinct features yet presenting similarities of form throughout the sample's library, hence enabling group classification.

Deeper observations with a microscope uncovered that warp and weft's tufts inhabit negative space in specific ways. This confirmed their singularity and unique characteristics. What was unexpectedly found concerns pictorial decisions made during the drawing process. Notably, initial line drawings dismissed negative space's visualisation as a planar surface. But filling the space with black made perceptible its material condition, i.e. gaseous state (chapter 04). This was interesting because areas free of black, i.e. non-drawn lines, portrayed yarns as surfaces, thus establishing a clear differentiation between empty (black) and occupied (white) space. In effect, black/white visualisation conveyed that both spaces are inherent components of a weave structure, and that occupied space should be considered as part of the notation system. Insights drawn from investigating negative space as a 'structure unit' led to exploring it within a full weave structure repeat. It was suspected that, unlike the square of the modern weave structure notation, negative space would not repeat itself in an identical manner. As presented in the discussion of case study (ii), because negative shapes present evident irregularities of outline, size and yarn tufts' behaviour within a repeat, a pattern of inaccurate repetition occurs. This means that as anticipated, negative spaces are similar yet are not identical; the parameter of unwavering regularity that repetition usually demands is therefore not respected. However, a grid-like matrix of fractured negative shapes was identified — exhibiting fluidity and chaos. This does not mean a lack of structure. Simply, it contradicts the current notation's rigid and linear aspect. It therefore confirmed the foreseen indication that this weave structure visualisation isn't adequate for automata's binary setup. Nevertheless, black and white's lack of contrast eliminated any sign of occupied and empty space's relationship. As a result, this visualisation confronted considerable limitations. Repetition, a core parameter of weaving, was indeed challenged. But if a weave structure visualisation through negative space cannot be seamlessly repeated length- and widthwise, what does it mean for woven textiles construction methodology? What are the implications of making cloth without uninterrupted repetition in the textile design landscape? What and who could it benefit? Additionally, the binary model on which the modern weave structure notation is based was maintained through colour — hindering the drafting of any conclusive insights in line with empty and occupied space's possible connection.

As stated in the methodology chapter (02), X-Ray CT scans can be interpreted in myriad ways depending on the treatment manipulation they undergo. A closer observation of non-treated X-Ray CT scans showed that when slices were animated, empty and occupied space appeared in a range of greys and that both types of spaces seemed to support and forge each other. As a result, X-Ray CT scans' blurry aspects identified the fuzziness of yarns — providing concrete evidence to include occupied space in the visualisation. Igoe's (2020) reflection on the fundamentality and agency of "edges, borders and surfaces as framing devices for textile designing" (p. 7) enabled an exploration of fluctuations between the material and immaterial character of cloth's "constituent parts" (p. 7). Here, 'immaterial' doesn't relate to Ingold's (2007) definition of material (chapter 04), in that it doesn't refer to an 'im' — from the prefix 'in-' (not) — material state. Rather, it is associated with a conceptual understanding of borders and surfaces' intimate relationship. Furthermore, the lack of visual acuity and shape definition depicted weave structure as an aggregate of elements; all part of a more complex whole. This remark, along with the limitation of black and white drawings, pointed towards the pivotal element of the research, that is, the potential of tonality. Practically explored in chapter 06, this therefore laid the foundation for investigating the apparent coexistence of occupied and empty space and the implications of such a synergy in uncovering a new understanding of weave

structure notation.

Manzini (quoted in Igoe, 2020) explains that, existing at the core of a surface, “the dynamic qualities” (p. 7) of its components should not be overlooked. That is to say, the idea of rigid boundaries framing a surface goes against the very definition of surface. It is instead understood as a planar bridge through which a myriad of activity and data travel from one constituent to another (Igoe, 2020). Following this rationale, as materials in opposite states, the thesis concludes that negative spaces and threads are borderless surface-interfaces communicating with each other. As part and distinct parts of a weave structure, holes and yarns shape one another, each affecting the space they take within the woven scaffold. They are material elements continuously in flux, whose mutual influence defines their equal value and inherent need within the whole weave geometry. This infers that this holistic relationship needs to be accounted for when drawing weave structure.The research thus proceeded to ask:

> What is this dynamic exchange? And why was it important to grasp in regards to weave structure visualisation?

8.3 Tonality — the role of grey nuances in an alternative understanding of weave structure construction

Experiments with grey through drawing and tracings revealed the colour to be synonymous with transition and intermediacy (chapter 06). This was conceptually underpinned by Klee’s (1921-1931) understanding of grey in his treatise on the genesis of form (section 6.2.1). The hovering character of grey as a midpoint of every complementary colour proposes that it is pictorially inherent to the stability and ‘equilibrium’ of an entire system. The thesis therefore suggests that the colour is tantamount to the aforementioned notion of ‘w(hole)’, in that grey embodies empty space’s relationship to weave structure as a network of systems. Truly, grey’s transitional and connective quality is compelling in accordance with holistic systems. Indeed, grey enabled visualisation of the characteristics of each part of the structure as well as their relationship to the organised construct. Drawings and tracings showed that grey’s nuance repertoire illustrates negative spaces’ varied features and portrays the move from empty to occupied space, be it direct or soft. Such a shift suggests that grey is a colour that expresses mobility. In addition to being a mediating colour, grey reveals itself as a channel for invisible, intuitive, experiential weaving know-how. By this the research means that, the maker's emotionally intelligent attitudes towards using craft weaving methods permits enhancing hand manipulation, thinking through making and tacit modes of doing, as opposed to manufacturing ones. This is furthered below (section 8.5). In other words, grey enables a holistic approach to interpreting the role of the hole in its relationship to the whole system, i.e. weave structure. Tonality thus conveyed that the colour should not be used as a representational tool but as an active and performative one, fostering holistic modes of making and thinking.

Grey drawings and tracings carry different visual messages. As examined in case study (iii), because drawings include black and white, occupied and empty space's identity is upheld. That is to say, they remain distinct systems, known to be in opposite physical condition. Yet the presence of grey portrays the two systems' interconnectivity and symbiotic coexistence. Conversely, tracings impede a differentiation between empty and occupied space because both systems appear in a range of medium to light grey tones — picturing little to no contrast. This is problematic because as exposed in chapter 07, for others, this visualisation technique is particularly unclear and prevents the viewer from recognising the draft as one of weave structure. However, while this is a valid argument, tracings further the reflection on grey as a transitional colour. Not only does yarn tufts' attitude shape negative spaces but empty space itself accommodates fibres to behave organically (e.g. slightly unspinning from yarn's original axis). As a result, could apprehending grey as mediator of an action be more adequate than understanding it as a colour-tool?

Conceptually, grey resonates with the realm of shadows. Indeed, yarn's wooly tufts do not only manifest themselves in solid form. Their shadows, projected onto negative space, open additional clues as to the interpretation of grey as a performative channel. By this the research means that, as interstitial spaces (Klee, 1921-1931) shadows can be interpreted as the passage from occupied to empty space. Equally, shadows also represent the nebulosity of grey and are therefore not truly about the colour itself. Rather, they are a realm in which the 'unseen' resides, whose indeterminacy and uncertainty enables tonality to prevail. This characteristic was mirrored in X-Ray CT imaging as an investigative method. Indeed, tonal contrast identifies substantial things, i.e. solid, liquid, that are not usually visible to the naked eye (e.g. composite material makeup) or are hidden elements situated under an opaque material (e.g. cancerous cells, bone fractures). Conversely, in this thesis X-Ray CT scanning was used to visualise elements of weave structure that are already invisible, i.e. holes. The method proved to be very compelling because, while the images generated didn't bring visual clarity, they opened up a line of questioning on the role of tonality in weave structure visualisation, leading to experimenting with drawing in grey tones.

As discussed in chapter 05 (section 5.2.3), the analysis of non-manipulated X-Ray CT scan instigated the idea that grey might have value in visualising weave structure and hence could uncover insightful information. What X-Ray CT imaging showed is that every single pixel counts, in the sense that each of them communicates valuable data and that, digitally, 'nothing' cannot exist. As a result, because each pixel carries equal value, hierarchy of function in weave structure does not matter in the virtual sphere. Parallel to drawings, grey nuances dismantle the nothing/something structure and the primacy of occupied space in the physical world. Likewise, as discussed in chapter 07 (section 7.1), group A's suggestion to use three different colours is an idea that could remove hierarchies of properties within weave structure notation. Yet, if weft is blue, warp is red and negative space is green, the interconnectedness of the three isn't visualised. In other words, grey's removal forgoes illustrating weave structure as a holistic system.

As such, drawings and X-Ray CT scans show that neither method is about grey. Rather they concern an expression of greyness. Tracings' messiness corroborated this argument because it appears that grey excludes the presence of negative space, in that one cannot identify whether the so drawn negative space is the now traced empty or occupied space. This phenomenon does not mean that the hole as 'structure unit' isn't an inherent component of weave structure. Rather, the language used to permeate its role is contested. In other terms, the hole isn't interpreted as a void within weave structure anymore. Instead, the greyed surface introduces the possibility of being beyond empty. Consequently, grey asks:

> What else is there? What else does negative space embody apart from a void in-between yarns?

8.4 Agency — the influence of empty space

Advancing that there is more to negative space than mere emptiness, suggests that its influence on other components, i.e. yarns, is inherent to understanding weave structure beyond hierarchy, perpendicularity, repetition variables and binary paradigm. As presented in case study (iii), this

considers empty space as having some form of agency — an idea also central to group B's discussion during the seminar (chapter 07). Indeed, participants suggested that the grey visualisation further interrogates the relationship between the void and its neighbouring yarns. They asked, "Out of which will is occupied space shaping empty space?" (participant B3). However, claiming that negative space has a 'will' suggests that it is able to make decisions as to the ways in which occupied space behaves, which goes against the idea of interconnectedness between the two spaces. Additionally, agency brings into question the boundaries of negative space, its role and context, that is to say, its relationship with its surroundings. As explained in chapter 05 (section 5.1.5), it is difficult to grasp, if not impossible, the physical limits of negative space because of its lack of front and back side. However, as Heinzel (2012) explains, a material surface comprises everything that is within, around and outside itself; hence suggesting that the hole must influence and be influenced by things outside of the whole woven surface (chapter 10). The thesis argues that the grey nuances of drawing and tracing do not notate a weave structure as it were. Rather grey helps find another way of looking at weave structure. Truly, tonality outlines the inherent difference between the current notation of weave structure and the actuality of woven cloth. By this the research means that grey's mediating character enables a depiction of woven cloth's behaviour — one that is continuously in movement, unpredictable and disordered. The perspective taken, i.e. through negative spaces in-between and within yarns, proposes to break away from a rigid representation of the linear weaving construction methodology in order to illustrate cloth's fluidity — in turn confirming the structural necessity of the hole in a woven textile's matrix. Grey tones thus bridge between weaving's symbolic system and woven textile — meaning that nuances point at the folding features of cloth that the modern notation does not visualise. This infers that, although cloth's qualities and properties are not outwardly communicated, the alternative weave structure visualisation accommodates engagement from the viewer. It isn't a code to be read but an illustration to be interpreted. It asks, what can the reader read from it?

The evolution of weave structure notation from the punched card system to the one used today remains a design tool for manufacturing. However, this thesis has shown that hands and the knowledge that they carry are the primal tool of the maker. As written in chapter 02 (section 2.7.2) and developed in chapter 05 (section 5.1.4.2), the hand's 'tool quality' is twofold. It is both the maker's instrument and an apparatus independent from the maker's own will. The former allows the maker to preserve authorship over the image because the aim is to visualise the object of study as it is. Conversely, the latter gives away the authorship to the image because while making, the hand drives the maker's movements — stemming from outside of the maker's own reasoning. For the image to gain authorship means that negative space's influential characteristic is visualised and hence, allows the hole to become the primal tool. This is true not only for notating and interpreting weave structure but also to visualise the knowledge contained in the hands of the maker. Here, the properties of the artifact, i.e. the hole, enable turning away from observing it as it is but instead, understanding what it can do, be or open.

The notion of authorship and who it 'belongs to', draws focus on the issue with representation. This thesis does not aim to represent empty space because, as stated in chapter 07, this is a humanly-driven action, which suggests that the maker-researcher already knows what they are looking to study and thus to represent. 'Representation' showcases an, albeit accurate, static presentation of the object of study, that doesn't necessarily impart novel elements of information. 'Visualisation', on the other hand, aligns with 'notation'. The former is associated with the idea of system and can often relate to communicating visual concepts and inputs, while the latter is a symbolic system that diagrams specific information regarding a set of data. Here, representing would suggest the depiction of a passive and fixed empty space — one that would forgo understanding the hole as a, albeit 'not here', material space in an opposite physical state than yarns. Visualising or notating on the other hand, identifies empty space as a dynamic material surface whose content reveals the conceptual and practical potential it encompasses; hence the choice to make this crucial differentiation.

As highlighted in chapter 07 (section 7.4), participants from group B associate 'agency' with 'beyond'. That is to say, for negative space to have agency, i.e. what the thesis refers to as holding an influential role, means that it can open possibilities 'beyond'. Such a term poses complex questions. 'Beyond' could relate to negative space's material condition, i.e. other than mere emptiness. Likewise it could suggest that the hole is a conceptual space in which interpretations of data are myriad. In other words, a space that enables exploring alternative understandings of weaving within and outside the discipline, hence broadening research horizons.

8.5 Alternative tool — communication, reading, analysing

During the seminar group A mentioned that (chapter 07, section 7.2) grey nuances provide a

useful way of indicating the location of empty space within an already produced woven cloth. The alternative weave structure visualisation thus communicates cues about the weave structure that was employed to weave a cloth. Likewise, although greyness hinders the readability of the notation system, it allows forensic analysis of a woven cloth. Thus, communication and observation are two properties that could be useful for structure evaluation and structure recording in textile conservation or archeology for instance. This illustrates empty space's agency as a post-weaving artefact — one that enables knowledge excavation from a technical viewpoint. On the other hand, grey tones offer a more organic way of interacting, observing and understanding weave structure. Here as an analytical method, the alternative weave structure visualisation does not serve the study of woven textiles. Instead, it supports employing craft methods as transferable knowledge to shift perspectives on weaving, which could be applied to other forms of study that embrace non-binary paradigms. Greyness outlines weaving's ancestral and fundamental knowledge, that is, the doer's intuitive ways of knowing and making, that which cannot be confined within the linearity of the grid. This craft approach, one that is led by materials — be them in-/tangible or in-/visible — could be practiced by other disciplines and transposed to other types of research. For instance, biological computing and other self-assembly systems that are shifting from traditional, mechanical and binary ways of thinking could benefit from such a perspective, in order to examine and interpret behaviours of other entities and their connectedness to the system within which they exist (chapter 10).

As a result, notating weave structure through greyness challenges the ways in which weaving know-how and its visualisation is understood and read. Furthermore, it questions behaviours and perspectives towards weaving as an engineering construct. The seminar (chapter 07) proved that others' interpretations vary. Indeed, groups A's participants reflected on the alternative weave structure notation as a visualisation and a recording tool, that is, a post-weaving mechanical apparatus. Alternatively, group B understood it as a data collection method for interpretation, analysis and shifting perspective. That is to say, an unmechanical tool to widen the avenues for weaving principles' application. In fact, they mentioned that in a medical context, differentiating the meaning between greys requires expert knowledge and is related to interpreting greyness (chapter 10).

8.6 Craft weaving methods

The seminar raised questions regarding the purpose of this new symbolic system within group A. For this cohort, it was difficult to envisage a notation that aims to step away from weaving's manufacturing principles and its potential benefits for the craft. This is interesting because it suggests that a non-binary paradigm is inadequate for the traditional weaving landscape. Nevertheless, their weaving knowledge lacked insofar that, had they not been told the meaning of the black and white squares of the current notational system, they would not have been able to understand how to produce a woven textile. What was unexpected is that they could not eclipse the idea of production, in the sense that weave structure notation equates to the generation of a woven product. For them, grey did not convey an alternative perspective on the craft. Its ambiguity confused the new notation's outlook for woven textile production. As the proposed visualisation is intended for professionals outside the weaving field to understand craft practices in weaving, it could enable other, more organic and non-linear ways of thinking and making things. The notion of perspective is crucial because the thesis does not aim to establish a new weave structure notation, meaning that the study is not about weaving and its notational system. Rather it is *for* weaving : while originating from a polar model for cloth construction, the visualisation developed promotes non-binary modes of thinking and making woven textiles. Weavers could equally benefit from such an holistic approach to the discipline in order to explore and propose other ways of engineering woven textiles — in turn contributing to the most ancestral form of cloth-making known to humankind. As a result, a less mechanical eye on weaving could have an impact on the future production of woven materials. In other words, going back to fundamental questioning of the knowledge contained within fabrics could impart other ways of approaching textile design research.

A critical review of the literature (chapter 03) showed that prior to the late Middle Ages there is no repository of any form of weave structure notation, which suggests that because of the lack of industrial landscape, an industrial script was potentially irrelevant (section 3.1.1). The modern weave structure notation is designed to fit the specification of the mechanised machine. Indeed, the matrix of coloured squares communicates weaving data in binary codes, that which is adequate for automata to function yet confines weavers to the limitations of the loom. As exposed in chapter 02, weaving is, to an equal degree, a technique of making and a framework of thought. Notably, this can be said of a myriad of creative disciplines, within textiles or other crafts including, among many, ceramics, or wood-working. However, the paradox that weaving embodies, i.e. the aforementioned rigid construct that shapes a soft woven product, enables a departure from a Cartesian model to shape a more nuanced one that embraces notions of instability and flux. Yet while weavers might be skilled at fashioning aesthetically and technically outstanding cloth, it does not imply that they are able or so inclined to challenge or even dismantle fundamental, traditional understandings of their craft. Today, weave structure notation is accepted and used as a design tool for manufacturing. Yet it limits makers applying their implicit and innate knowledge, hence silencing such wisdom acquired through mistake, risk taking, weaving, unweaving, reweaving — that is, learnt through practice and experience. As presented in chapter 03 (section 3.4.1), this idea of knowledge acquired through the experience of making and intuitive experimentation with materials relates to the maker's emotionally intelligent attitudes towards their practice. Here, being attuned to negative space's properties and functionalities as a material with which to experiment, enables a more intelligent and holistic approach to the study. As a result such attitudes enable hand manipulation and creative intervention — in turn enhancing craft weaving methods instead of manufacturing ones. Beyond weaving and more broadly, the field of textiles, this also concerns other creative disciplines as it proposes to embrace intuitive knowledge for doing. By departing from a focus on the outcome and a solution-oriented mindset pre-making, the approach might enable individuals to engage with material interactions along with practices of doing, undoing and redoing. Practice revealed that repetition is a variable that cannot be respected in weave structure visualisation through negative space, because of the shape's irregular characteristic. As such, in the current textile design landscape, which prioritises manufacturing methods over tacit ways of designing, such an approach could be considered non-productive. By this the research means that, from an industrial standpoint, the proposed visualisation would not produce concrete products or innovative outputs. However, what craft weaving methods propose is an 'error-tolerant' system of procedure, in the sense that it goes against the parameters of hierarchy, binarism, rigid orthogonality and instead adopts unpredictability, uncertainty and chaos. It is this shift from traditional weaving methodology that enables research to open the discipline to others. Here, as a transferable form of knowledge, craft weaving practice encourages alternative, more holistic perspectives, that prioritise organic and irregular ways of doing.

It is valid and relevant to criticise the current weave structure notation and its limitations. Nevertheless, this thesis demonstrates that the restriction brought about by mechanical advancements is essential to generate new perspectives. Truly, in order to bend the constraint, the metronomic structure of weaving construction needs to be respected and followed. This is what greyness provides: a space to push the boundaries of the grid while acknowledging its

necessity. The notion of 'w(hole)' in weaving presented at the beginning of this chapter is a defining feature of weave structure as an antithetical construct, in that it reflects the symbiotic relationship of the woven hole and the whole woven matrix. 'Hole' illustrates the underseen, forgotten and unexplored elements of a structured system both practically and conceptually. 'W(hole)', outlines the incorporation of holes as well as their inherence within that system. It proposes a system that aims to disrupt the known and established modes of thinking and doing. Considered as 'unstable' because of the irregular and unpredictable behaviour of its component, 'w(hole)' is a notion that sees structure systems as alternative forms of scaffold. Such a tie conveys that, conceptually woven textiles carry both the maker's experience, intuition, interaction with materials and other things 'beyond' human reasoning; and practically, the presence of the gaps in-between threads is inherent to cloth's stability. Yet the story of 'whole' and 'hole' does remain a mystery — one that might lie at the heart of weaving as a craft practice.

09

Conclusions

Original contribution to knowledge

09 Conclusions and original contribution to knowledge

This practice-led PhD has examined the role and value of negative space in weave structure visualisation. Rather than positioning empty space at the heart of the thesis, research has investigated it theoretically and employed it as a practical tool — one that enables a holistic approach to weave structure — in order to develop an alternative understanding of their visualisation. The resulting conclusions and their contribution to knowledge are presented below.

(i) A visualisation of weave structure that questions weavings' binary model

The development of a new way of picturing weave structures challenged the binary model of the modern notation system. Although the black / white polarity was maintained, in order to distinguish empty from occupied space, grey nuances enabled the two seemingly incompatible systems to come together. Drawings and tracings employed grey as a transitional colour that illustrated the systems interdependence and coexistence as part of a complete weave structure. Additionally, visualisation in grey shades communicates the fact that uncertainty and unpredictability can be valuable data in the engineering of woven textiles. As the proposed weave structure visualisation does not respect weaving's parameters, including hierarchy, repetition and orthogonality, it is a system that encourages irregularity. This is pertinent within today's research landscape which looks into the ways in which 'things' are put together (e.g. self-assembly systems, biological computing), be they tangible or intangible (chapter 10). This perspective could therefore have value for the potential development of novel textile assembly processes.

(ii) Propose an alternative weave structure visualisation

The alternative weave structure visualisation illustrated the value of weavers' experiential know-how and intuitive ways of making. By seeking to depict non-mechanical elements within weave structure construction, the proposed visualisation evidenced the importance of a holistic perspective on depicting weave structure. As it prioritises material-led ways of making, the weave structure visualisation developed acts as a 'craft' tool as opposed to a manufacturing one. That is to say, one that fosters more nuanced and organic ways of doing and thinking as opposed to linear and binary ones — henceforth highlighting the benefit of craft weaving methods and encouraging their use in the creation of textiles.

(iii) Evidence of negative space's role and value

The inherent role and value of negative space in weave structure visualisation has been explored through a conceptual inquiry into empty space as a 'material' constituent of a woven textile matrix (chapter 04). Substantiated by its examination as a 'structure unit' and within a 'repeat' (chapter 05), research found that irregularity and non-identicality is a distinctive feature of negative space. Its repetition, albeit inaccurate, formed a cohesive sequence which introduced the potentiality of a topology of empty space. In doing so, this discovery affirmed that occupied space, i.e. yarns, is equally intrinsic to the visualisation of weave structure.

(iv) Understanding the holistic relationship of the woven 'hole' to the 'whole'

Stemming from an orthographic reflection, the notion of w(hole) identified the woven hole as part and a part of a whole weave structure. This permits the understanding of weave structure as a holistic network of systems — one in which two contrary systems, namely occupied and empty space, function in symbiosis, due to their interaction as well as their relationship to the structured construct itself. Additionally, the notion of w(hole) proposed another way of thinking about weaving's symbolic system as a communication apparatus. It facilitates novel interpretations, engagement and interactions, for and beyond the craft, as opposed to imposing one way of reading weaving data.

(v) Understanding X-Ray CT scan as a tool to bridge between disciplines

X-Ray CT scanning has shown itself to be a fruitful method for understanding and visualising the interconnectivity of two different systems, whose synergy characterises weave structure. Significantly, weave structure notation in grey nuances is particularly insightful as a way to understand X-Ray CT imaging, here, as a medium (chapter 08 and 10). This revealed that the alternative weave structure notation can act as a tool to bridge between disciplines.

(vi) Opening up weaving specialism to interdisciplinary research

The alternative perspective on weave structure visualisation illuminated the need for the craft to flee from its limited 'traditional' scope towards collaborative practices and to open its specialism to interdisciplinary research. As a result, the proposed way of visualising weave structure, including potential others, can enable a demystification of the discipline and decouple it from its mechanical process. This is significant for the current research landscape, in which designers are increasingly required to think in non-linear ways in order to depart from manufactured ways of designing. In effect, extending the reach of weaving to other disciplines could have a significant impact on future economic models based on a localised as opposed to an industrialised mode of production; potentially even playing a role in helping confront the climate catastrophe to which the textile industry is a significant contributor.

9.2 Original contribution to knowledge

In its present condition, weave structure notation does not indicate woven textiles' functional and aesthetic characteristics. The proposed visualisation illustrates a more holistic understanding of cloth construction and therefore gives clues as to possible other assembly processes for future textiles — be them tangible (physical realm) or intangible (virtual realm) — away from the limitations imposed by the current notation.

Adopting emotionally intelligent attitudes toward the craft enabled this holistic approach and gave rise to the notion of w(hole), which identifies weave structure as a network of antagonistic systems existing in symbiosis. Additionally, this perspective enabled an original exploration into weaving because of its unique methodology: bringing emotional intelligence within the scope of its intellectual framework.

Such a notion evidenced the value of weaving's paradox as a textile construct, in the sense that its inherently binary construction methodology has the ability to develop non-binary modes of doing and thinking. As this work is the first investigation into weave structure notation that questions one of the most fundamental textile engineering methodology known to us, the alternative approach has value in inspiring, encouraging and informing the development of new weaving construction methodologies.

Visualising occupied and empty space together confirmed the value of negative space in weave structure notation and illustrated another form of weaving knowledge permeation. This highlighted the key role the proposed visualisation could potential have in bridging between disciplines — enabling novel perspectives on the analysis of other modes of communicating data within and without the textile realm.

Weaving has long been a closed discipline and that continues to be true today, limiting its presence in interdisciplinary research. Yet, as evidenced by this research, the craft as a way of thinking, not only has value within the wider research landscape, but can also play a crucial role for the development of alternative, non-linear and organic modes of production.

10.

Future avenues

10 Future avenues

10.1 Observing empty space within yarns at the quantum scale

The construction of woven cloth does not solely depend on weave structure. As explored in chapter 03, materials hold an intrinsic influence on the quality and properties of a textile; often, material decisions influence weave structure choices. Microscopies and X-Ray CT scans revealed small voids within the yarns of most samples; hence identifying a possible topology of negative space. One promising area of research is therefore observing weave structure at the quantum scale to explore the role and value of the void within yarns and fibres. The findings of this research indicate that occupied and empty space are interdependent and that woven cloth cannot exist without one or the other. Thus, at the nanoscale, does such a symbiotic relationship apply? And does it affect the properties and qualities of the full weave structure? That is to say, does empty space have a specific role as in the stability of the woven textile at different scales? And if so, could drafting a weave structure notation that includes empty space at the macro ('structure unit'), micro (yarns) and nano (fibres) scales help develop another way of looking at the construction of weave geometries? Potentially, the quantum scale could enable the observation of the possible content of negative space itself. Indeed, the invisible 'things' that exists in the air that surrounds textile material might have value in deepening the understanding of the hole as a material surface; and hence its relationship to the whole weave structure. This could offer new possibilities into the ways in which makers use, understand and work with materials; therefore opening new perspectives on the ways in which woven cloth is created.

10.2 Understanding negative space in the virtual space

This thesis has shown that understanding the 'unseen', that is, invisible material surfaces can reveal valuable pieces of information about weave structure. Today digital software enables the grasping of the "digital materialities" (Søyland, 2015, p. 125) of textiles, which in fact refers to what is visible in the material world, as opposed to what is not seen. However, while empty space within weave structures is indeed not outwardly visualised and thus disregarded, software programs cannot avoid identifying its presence because each pixel carries weaving data, including the absence of solid material (chapter 08). Thus within the transition from a material-only world to a digitally-only one, further challenges arise relevant to negative space's role in an alternative environment. What are the virtual abilities of negative space as part of a digital weave structure? What can it uncover about the digital woven cloth? And what can it do or be in an immaterial environment? These questions suggest that visualising the hole virtually could make available new ways of approaching textile design research that embrace existing notions of "digital materialities" (ibid.) that are yet unintelligible and unforeseeable.

10.3 Model for a new perspective on bioengineered textile materials

Together with establishing the vital role of negative space in weave structure, the possibilities of visualising all material components of a woven construct proved to be a fruitful way to open the craft to interdisciplinary research. Nature has long been an inspiration for design and engineering. The 1990s saw the emergence of synthetic biology, which identifies a new way of designing with nature in mind by redefining, reorganising and redesigning organisms' behaviour — granting them new capabilities within a constructed structured system (Cameron, Bashor and Collins, 2014). As a design framework, biodesign therefore utilises organisms' functionalities and properties to solve engineering problems and create optimised new materials. The design of biobased materials stems from visible and tangible entities, including mushroom mycelium or bacterial cellulose, which, through different bio-processes, 'grow' materials (Cogdell, 2020). A new branch of research into the more-than-human paradigm proposes to observe the behaviour of entities as opposed to using them as design resource-tools. Thus, an emerging opportunity for new research into bioengineering could be that of pursuing the functionalities and capabilities of negative space within organisms' structural makeup, i.e. considering the hole as a more-than-human entity. In other words, instead of engineering new materials from an entity's solid components, it could be valuable to apprehend material 'growth', for lack of a better word, from the empty space within organisms. This could enable novel perspectives on building bio-based textiles that stem from craft practices — fostering interaction with all materials elements of any entity, as opposed to designing for product creation. It could, in turn, help address the harmful environmental impact of textile making.

10.4 Tool to interpret greyness

10.4.1 Analysing living organisms behaviours

The experimental investigations illustrate the benefits of developing a non-binary notational system that stems from a binary construction methodology — here weaving — in order to inform alternative perspectives for the discipline. The field of biological computation — i.e. the use of living organisms to undertake processing — and its analogue computational biology — i.e. the generation of frameworks that follow cellular processes — (Werner, 2022) is constantly developing computational systems that behave like living entities and therefore act in holistic ways as opposed to binary ones. It is notable that much of the digital imagery for analysing living cells' behaviours and functions appears in grey shades, prior to undergoing technical manipulations; thus requiring expert knowledge to understand the data (figure 10.1). The interpretation of such imagery relies on STEM methods. However, this research has shown that employing craft methods can impart other approaches to data analysis that favour intervention and intuition; henceforth embracing unpredictability and unknowability — parameters relatable to living organisms' behaviour.

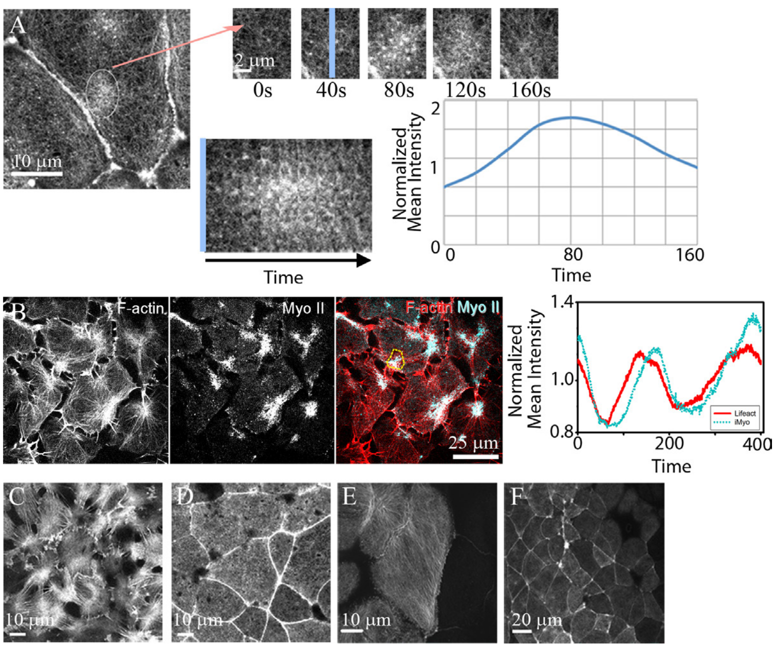


Figure 10.1
'Kinetics and diverse morphology of actomyosin contractions in Xenopus laevis embryos' from Miller, Harris, Weaver, Ermentrout and Davidson (2018)

10.4.2 Artificial Intelligence (AI) medical image recognition training

In medical research, new developments in AI medical image training are rapidly being made. The potential of AI tools to improve accuracy and optimise performance for complex illness diagnosis (e.g. cancer, neurological disorders) can have a considerable impact on providing better healthcare (Khalifa, Albadawi and Iqbal, 2024). The alternative weave structure visualisation in grey nuances was found to be a useful tool to interpret this research's X-ray CT scans. Thus as a connecting tool between areas of studies, it could be a useful resource for interdisciplinary research beyond creative disciplines.

10.5 Diagram — furthering weave structure notation

10.5.1 Oral knowledge

Greyness questions the value of notated weaving knowledge and skill mediation. The findings indeed highlight that grey's ambiguity and visual fluidity favour intuitive interpretation over straight-forward readability. If weave structure notation ever existed pre-late Middle Ages (chapter 03, section 3.1.1), stating that weaving knowledge and skills were implicitly transmitted through observing and making only would suggest that learning was imitative. This forgoes symbolic intelligence which, according to Ingold (2011), humans require for deliberate form making. However, language was the initial symbolic system for knowledge permeation (Margolis, 1978, cited in Ingolld, 2011). With this in mind, the idea of non-written notation is brought to the fore in that early symbolic systems of weaving processes could have existed in oral forms. This introduces the potential of a sound-based weave structure notation instead of a visual one. It could encourage other approaches to cloth-making that surpass mechanically following a set of instructions — in turn enhancing other intelligent ways of using craft weaving methods.

10.5.2 Non-Western notation

This thesis' findings stem from a Western-centric understanding of weave structure notation. There, any form of written material, including weave structure notation, is read from left to right. While the standardised matrix of black and white squares is used across the world in industrial environments for automata to function, how do other cultures notate weaving techniques and processes? For instance, Japanese culture reads written materials from top to bottom and right to left. Examining whether early and current traditional modes of notating and reading symbolic systems are applicable to weaving across cultures, could cultivate the worth of craft weaving methods as a transferable form of knowledge.

10.5.3 Weaving and music

The insights drawn from this study authenticate the proposed alternative weave structure visualisation as a tool to bridge in-between disciplines. Going back, once again, to the late-Middle Ages, the notation then drafted resembled the stave of a musical score (chapter 03, section 3.1.3). Akin to oral ways of transferring weaving knowledge, some unconventional music notation challenges the ways in which rhythmic sound is interpreted (figure 10.2). Such symbolic systems do not abide by the current standardised one, meaning that the musicians are left to decode the music in organic ways. The convoluted characteristic of this thesis' weave structure notation in grey nuances aligns with such musical diagrams, in the sense that the possibilities of interpreting 'activity' through time and space are myriad. As such one can wonder whether the interlacement of warp and weft must begin at the bottom left end corner for cloth to be stable and usable. Here, textile making could be dependent on the weaver's 'understanding' (chapter 03, section 3.4.2) of weaving as a craft practice — in turn encouraging alternative ways of weaving cloth and interacting with materials that remain undiscovered.

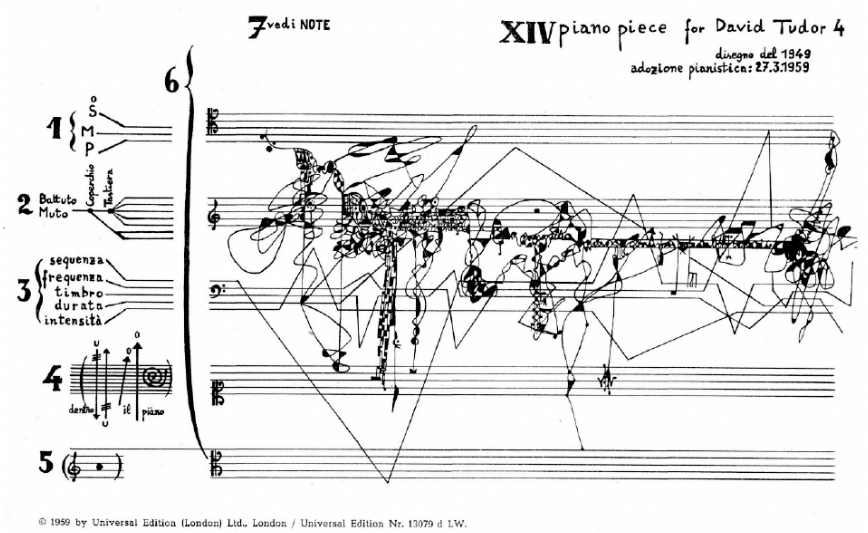


Figure 10.2
'XIV piano piece for David Tudor 4''
from Deleuze and Guattari (1987, p. 3)

Appendix A

Samples technical sheets

Technical Sheet

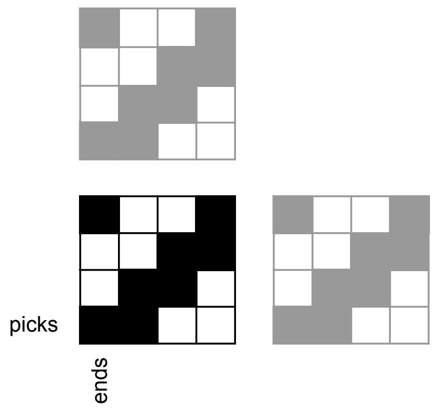
Yarn specifications

	Leno warp	Straight warp	Weft
Composition .	silk	silk organzine	Itaca Nm 14 100% viscose
Yarn Count .	120/2 Nm	60/66	n/a
Supplier .	Devere Yarn (UK)	Devere Yarn (UK)	RCA yarn ressource store

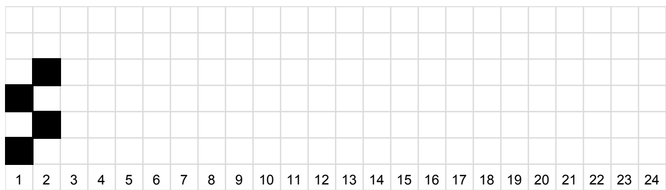
Sample specifications

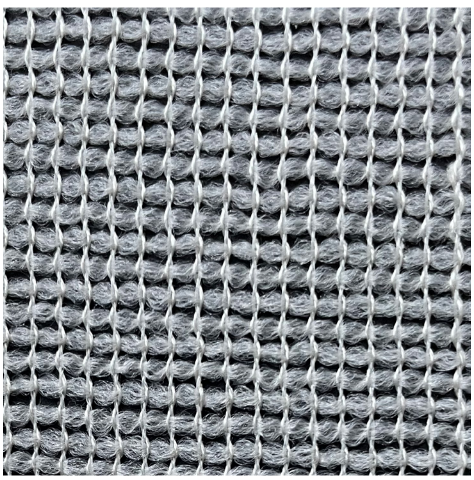
Width . 9cm
Length . 12cm
N* of paquets . 1 paquet repeated x40
Reed . 36 / 3 dents

Drafting plan



Weave structure





Appendix A2 — Sample S2

Technical Sheet

Yarn specifications

	Leno warp	Straight warp	Weft
Composition .	paper yarn	paper yarn	paper yarn
Yarn Count .	1/40 Nm	1/60 Nm	1/40 Nm
Supplier .			

Sample specifications

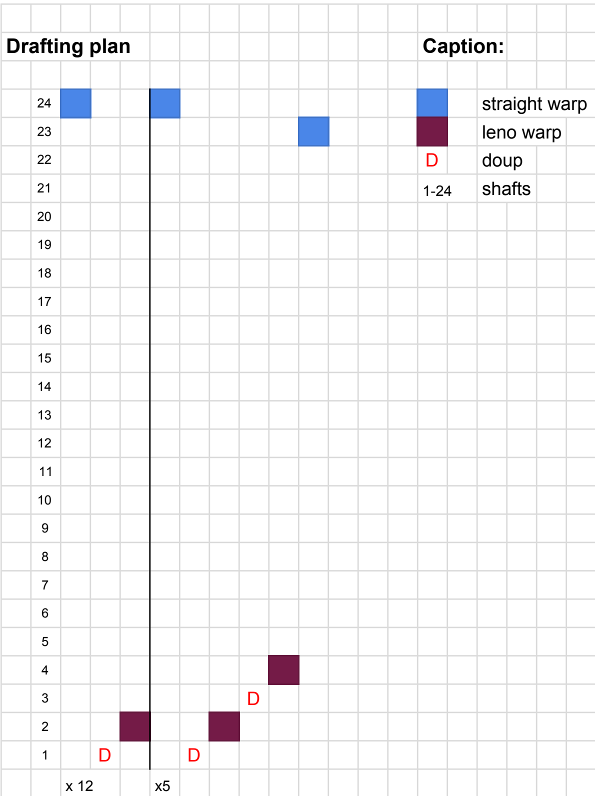
Width . 10cm

Length . 16cm

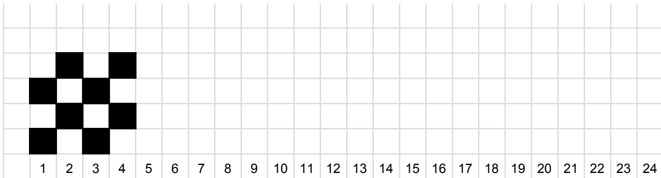
N* of paquets . 1 paquet x12 + 2 paquets x5

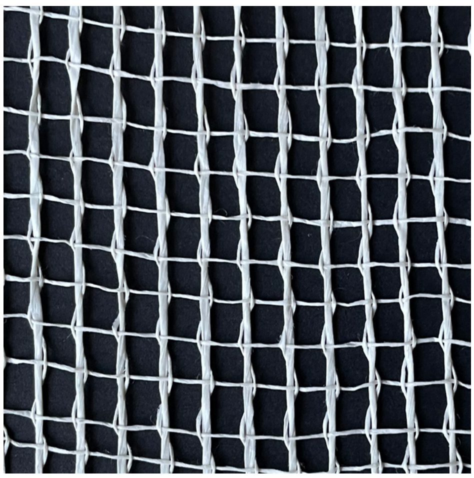
Reed / paquets spacing . 10 / 2 dents

Drafting plan



Weave structure





Technical Sheet

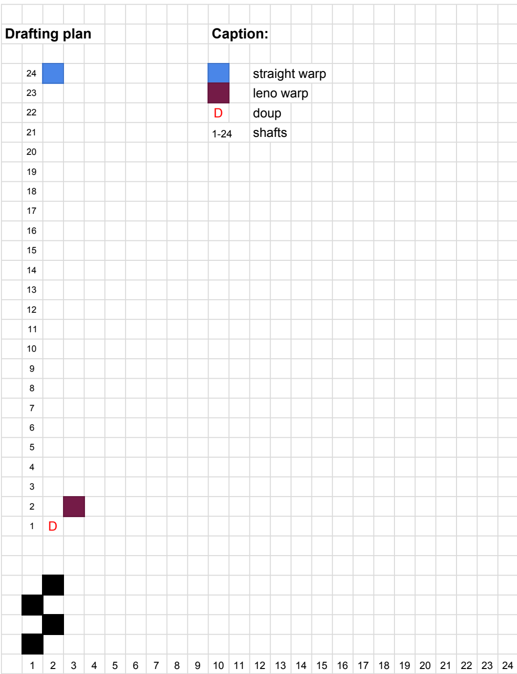
Yarn specifications

	Leno warp	Straight warp	Weft
Composition .	Como silk	Grammont 100% linen	Scarlett 100% Nylon
Yarn Count .	50/70 Nm 4.5	Nm 2600	Nm 1.6
Supplier .	RCA yarn ressource store (all)		

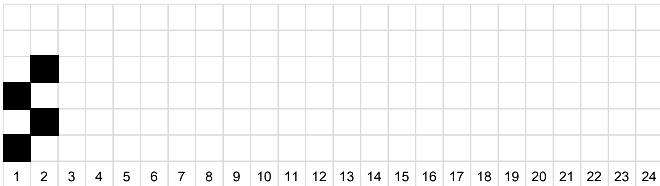
Sample specifications

Width . 11cm
Length . 10cm
N* of paquets . 1 paquet x12
Reed / paquets spacing . 8 / 2 dents

Drafting plan



Weave structure



Technical Sheet

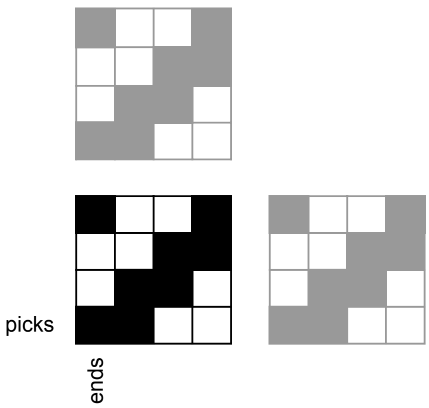
Yarn specifications

	Leno warp	Straight warp	Weft
Composition .	silk	silk organzine	41% alpaca 41% super wash wool 18% nylon
Yarn Count .	120/2 Nm	60/66	1/7.5 Nm
Supplier .	Devere Yarn (UK)	Devere Yarn (UK)	RCA yarn ressource store

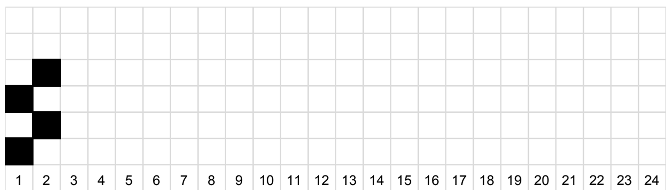
Sample specifications

Width . 11cm
Length . 11cm
N* of paquets .
Reed / paquets spacing . 36 / 3 dents

Drafting plan



Weave structure notation (weaving plan)



Appendix A5 — Sample S5 . Kinnasand, Twister 0001

Technical Sheet

Yarn specifications

	Leno warp	Straight warp	Weft
Composition .			
Yarn Count .	unknown (all)		
Supplier (sample) .	Kvadrat Kinnasand, Dater 0001		

Sample specifications

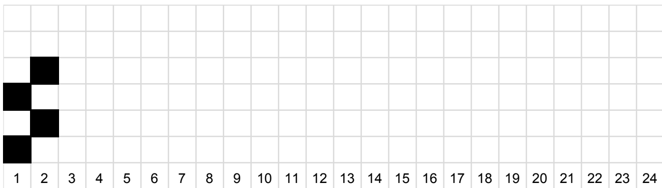
Width . 22cm
Length . 15cm
N* of paquets . n/a
Reed / paquets spacing . n/a

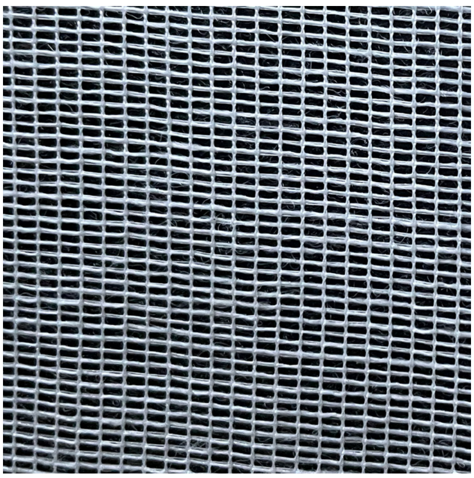
Drafting plan

Unknown

Weave structure notation (weaving plan)

from sample analysis





Appendix A6 — Sample T1

Technical Sheet

Yarn specifications

	Leno warp	Straight warp	Weft
Composition .	silk	silk	Como silk
Yarn Count .	120/2 Nm	120/2 Nm	50/70 Nm 4.5
Supplier .	Devere Yarn (UK)	Devere Yarn (UK)	RCA yarn ressource store

Sample specifications

Width . 11cm

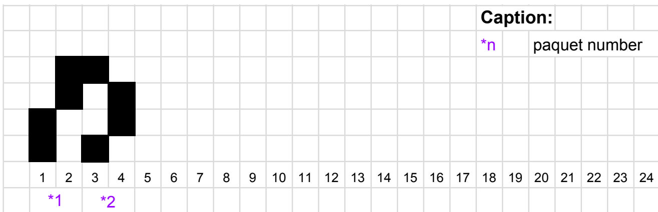
Length . 10cm

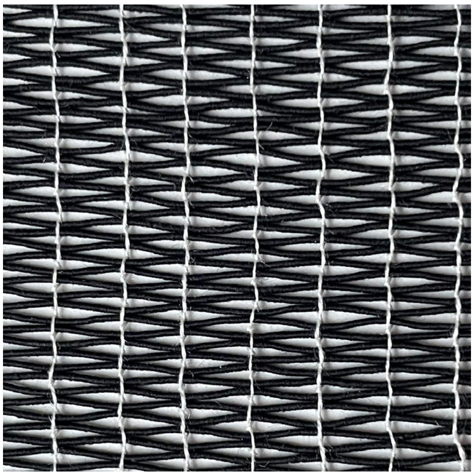
N* of paquets . 1 paquet repeated x20

Reed / paquets spacing . 36 / 4 dents

Drafting plan

Weave structure notation (weaving plan)





Appendix A7 — Sample T2

Technical Sheet

Yarn specifications

	Leno warp	Straight warp	Weft
Composition .	paper yarn	paper yarn	paper yarn
Yarn Count .	1/40 Nm	1/60 Nm	1/40 Nm
Supplier .			

Sample specifications

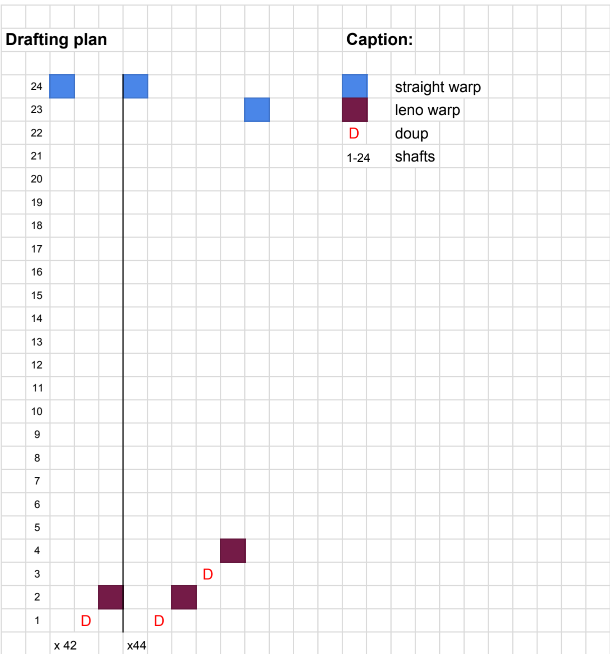
Width . 11.5cm

Length . 15cm

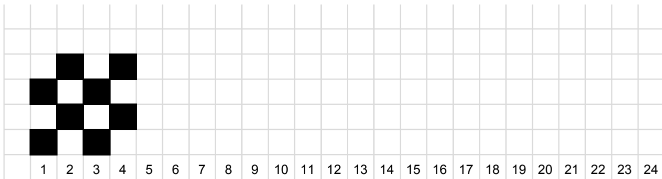
N* of paquets . 1 paquets x42 + 2 paquets x22

Reed / paquets spacing . 10 / 1 dent

Drafting plan



Weave structure notation (weaving plan)



Appendix A8 — Sample T3

Technical Sheet

Yarn specifications

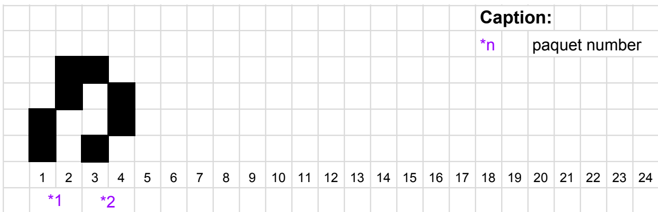
	Leno warp	Straight warp	Weft
Composition .	silk	silk	Topkid 67% superkid mohair 3% wool 30% polyamide
Yarn Count .	120/2 Nm	120/2 Nm	Nm 1000
Supplier .	Devere Yarn (UK)	Devere Yarn (UK)	RCA yarn ressource store

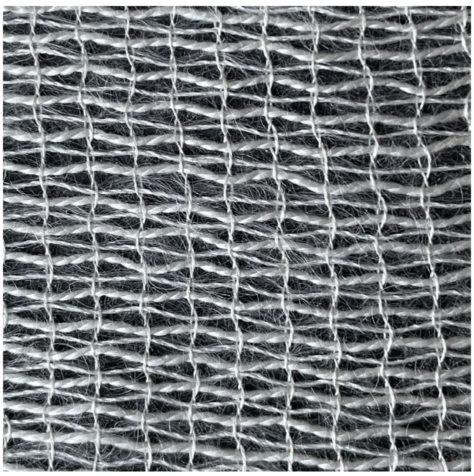
Sample specifications

Width . 11cm
Length . 10cm
N* of paquets . 1 paquet repeated x20
Reed / paquets spacing . 36 / 4 dents

Drafting plan

Weave structure notation (weaving plan)





Appendix A9 — Sample T4 . Kinnasand, Twister 0001

Technical Sheet

Yarn specifications

	Leno warp	Straight warp	Weft
Composition .	100% Trevira CS polyester (all)		
Yarn Count .	unknown		
Supplier (sample) .	Kvadrat (Denmark) Kinnasand, Twister 0001		

Sample specifications

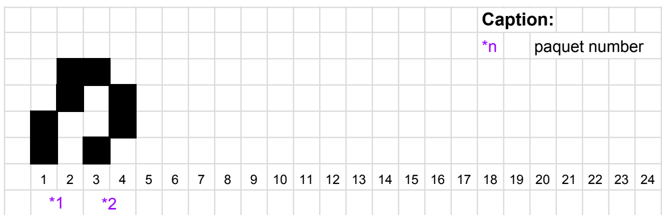
Width . 15cm
Length . 21cm
N* of paquets . n/a
Reed / paquets spacing . n/a

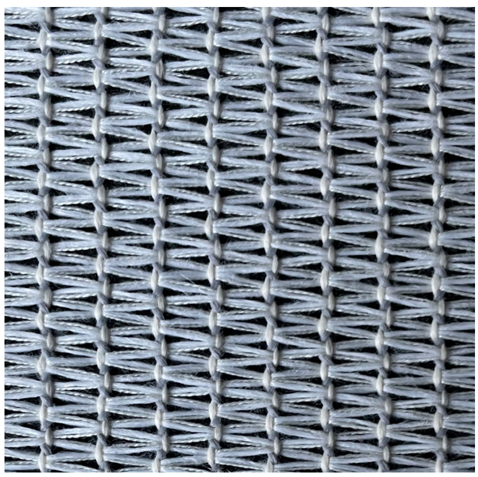
Drafting plan

Unknown

Weave structure notation (weaving plan)

from fabric analysis





Appendix A10 — Sample O1

Technical Sheet

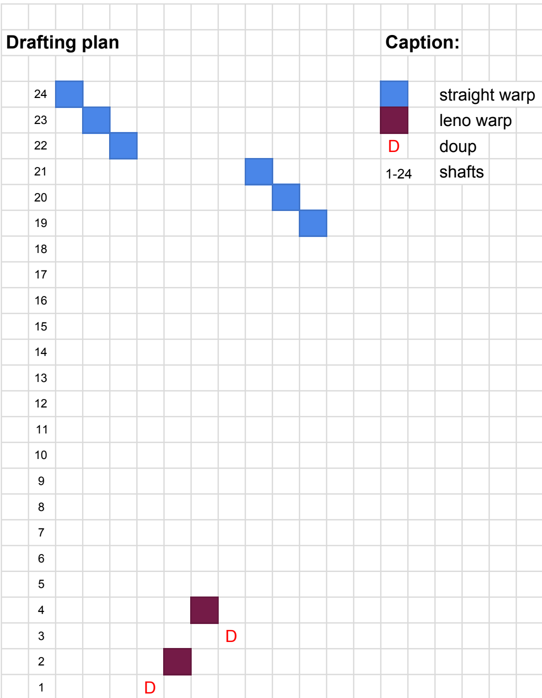
Yarn specifications

	Leno warp	Straight warp	Weft
Composition .	silk	silk organzine	Miele 65% cotton 35% nylon
Yarn Count .	120/2 Nm	60/66	Nm 7000
Supplier .	Devere Yarn (UK)	Devere Yarn (UK)	RCA yarn ressource store

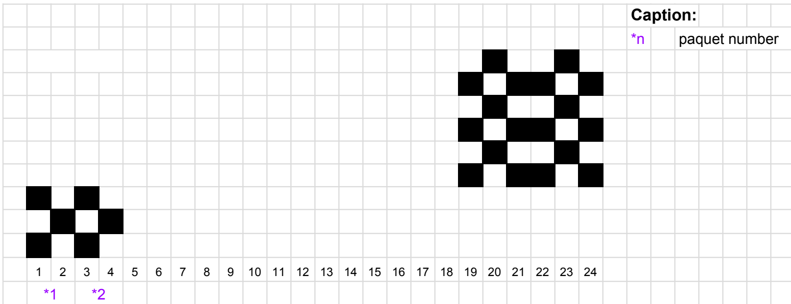
Sample specifications

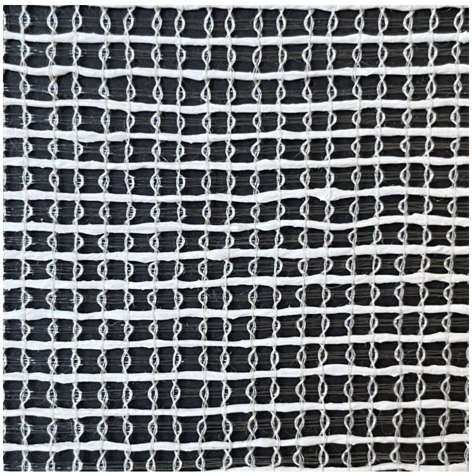
Width . 11cm
Length . 11cm
N* of paquets . 2 paquets repeated x20
Reed / paquets spacing . 36 / 3 dents

Drafting plan



Weave structure





Technical Sheet

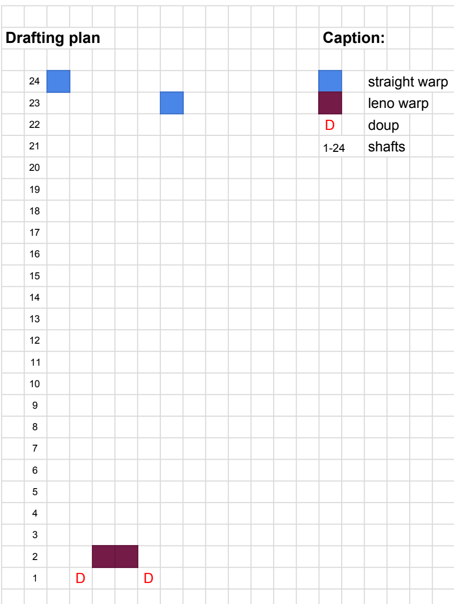
Yarn specifications

	Leno warp	Straight warp	Weft
Composition .	silk	silk organzine	silk organzine
Yarn Count .	120/2 Nm	60/66	60/66
Supplier .	Devere Yarn (UK) - all		

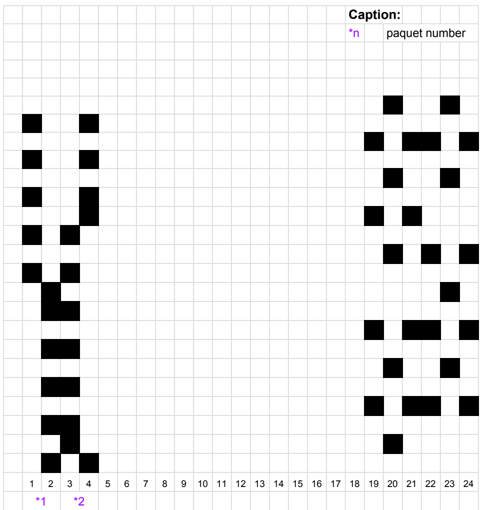
Sample specifications

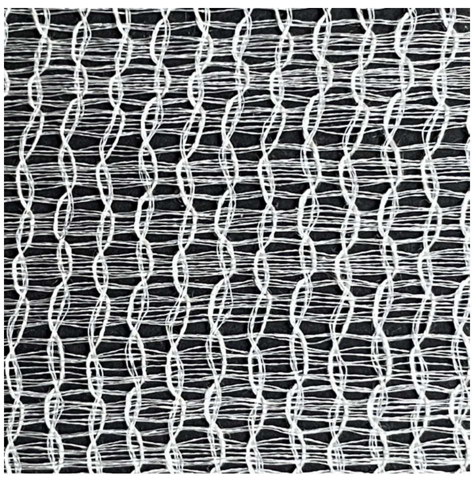
Width . 11cm
Length . 10 cm
N* of paquets .
Reed / paquets spacing . 36 / 4 dents

Drafting plan



Weave structure





Appendix A12 — Sample O3

Technical Sheet

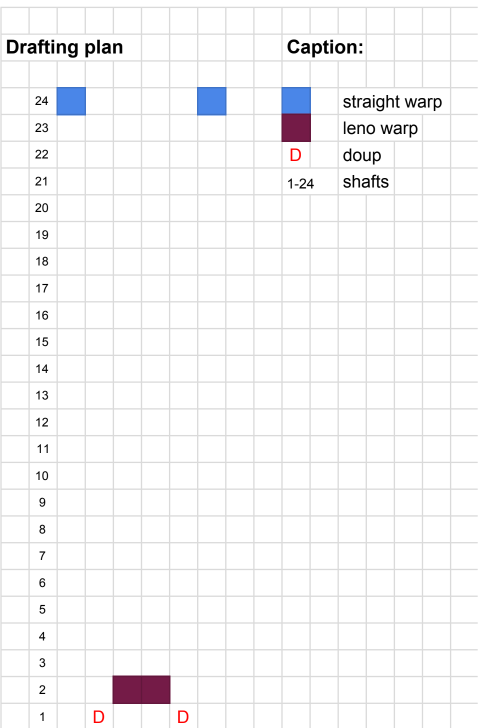
Yarn specifications

	Leno warp	Straight warp	Weft
Composition .	silk	silk organzine	Gommina 20% cotton 50% polyurethane 30% viscose + Celluloide 100% nylon
Yarn Count .	120/2 Nm	60/66	3200 Nm + 1/140 Nm
Supplier .	Devere Yarn (UK)	Devere Yarn (UK)	RCA yarn ressource store

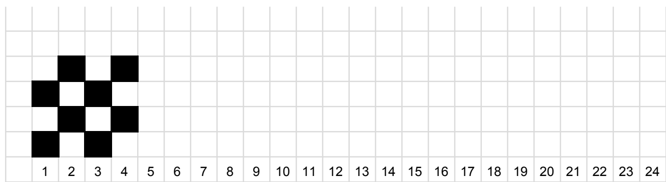
Sample specifications

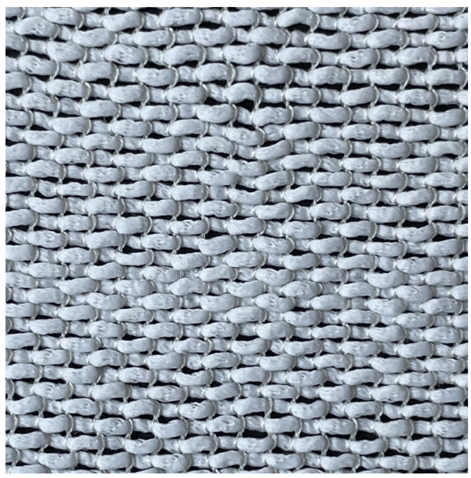
Width . 10 cm
Length . 11.5 cm
N* of paquets . 2 paquets repeated x20
Reed / paquets spacing . 36 / 2 dents

Drafting plan



Weave structure





Appendix A13 — Sample O4 . Charles Erwin, Helios

Technical Sheet

Yarn specifications

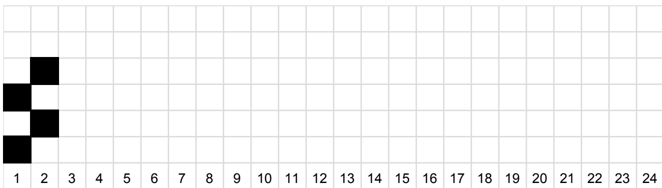
	Leno warp	Straight warp	Weft
Composition .	100% polyester FR (all)		
Yarn Count .	unknown (all)		
Supplier (sample) .	Charles Erwin		

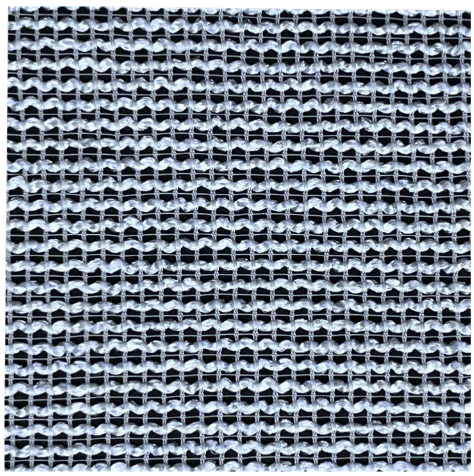
Sample specifications

Width . 14.5 cm
Length . 14.5 cm
N* of paquets . n/a
Reed / paquets spacing . n/a

Drafting plan
Unknown

Weave structure
from sample analysis





Appendix B
Online seminar transcript

In this online seminar, participants were asked to engage in a discussion regarding the drawings I had showed them (chapter 07). The transcript of the conversations is writen below.

Group A fascilitated by Participant *8

Participant A4: How did everyone find that exercise? I kept switching between (…) I kept switching my answers.

Participant A1: I think the first two, questions right, were easier. Much easier, at least to guess.

Participant A4: I know I confidently ask what the notation squares were but that didn't help me at all, understanding the direction the weft thread is moving in. Didn't seem to register with the coloured squares.

Participant A3: I think it could work but you need three colours, white, red and blacks. One for the void, one for the longitude and one for umm, the other one. So if you use three colours, I don;t see why it couldn't work. I don't know, I'm just… I think it's because I think of cellular automata and funnily enough, the things I've been doing with it, I've been using three colours. hmm to produce these maze-like structures but hmm. I don;t know, it's just a bit of a coincidence really.

Participant A2: I tried to figure out a 'w' on the third image but I couldn't figure out which ones were together.

Participant A4: The thing is that I kept seeing when examining different parts of the reference woven fabric. I don't know if it was just my brain playing tricks on me, but I kept seeing how they could associate with some of the other drawings as well. So [redacted] you mentioned that the notation reminded you of cellular …

Participant A3: Yeah cellular automata. It's basically just squares that have certain rules, whether they live or die. But yeah it reminded me of that. But I found a lot of these are kind of like X-Rays. Now I'm looking at the void, the holes, air space.

Participant A4: I think her inclusion of grey and focusing on that middle space at the end. I'm guessing that's what she's referring to as alternative notation. How do we think that kind of compares to the standard.

Participant A3: I'm not keen on the grey

Participant A2: I'm also not keen on the grey

Participant A3 : It's wishy-washy. It's not (…) I like a bit of contrast.

Participant A1: Yeah as soon as you said the idea of using three colours, it really resonated. The grey is just too hard to read and differentiate I think.

Participant A2: If we have to compare the white background versus the black background, I would say black background is much more clear for me, in my eyes. Because the threads are too thin.

Participant A4: I think what's clear is that the void needs to be included on the notation so there's an option of grey, there's an option of adding a third colour to the standard. I think what resonates is that the void should be represented in some ways. I think what makes me (…) what I ponder about is (…) I think that makes sense because you're drawn to the void. Even if I don't have any weaving knowledge or expert knowledge, you're putting, you're bringing these two threads together, to kind of erase the void, to create the fabric, "erase the void" is, obviously the gaps are still there. But it makes sense to me conceptually. I'm just trying to understand what would be the best representation of that.

Participant A3: I think maybe the void could be white and the other two black and red, whichever way, I think. In my opinion but you know, that's just me.

Participant A1: So this system that Ariane has come up with, the void is one colour and the warp and weft are a different colour but the same as each other right. So that maybe is what we're fixating on as being a problem. She needs to maybe put as much weight on the warp and the weft as individual entities as of the void. And that might help us to see the structure, to visualise the structure a bit better. Does that seem accurate?

Participant A3: That's right and I think it helps with the layering what goes over, what goes under.

Participant A4: I guess one question I have is what's the purpose of this notation. Because she asks in the 3rd question, do you think it might be suitable for the machine? And for me that notation implies a specific goal. Is to communicate what needs to be threaded or woven, not using the right terminology. But I think in that context I can understand that you have to represent the weft and the warp. And then representing the void could potentially unlock maybe better understanding or new possibilities in terms of woven patterns. I'm wondering whether if the goal of the notation changes perhaps to unlock imagination for new weaving and thinking about that. Then does that determine what gets represented? The question here is "notation meaning (...)?" or "for what purpose are we notating?"

Participant A2: If we can consider the whole structure as a 3D space and view the computer direction of how the weaving pattern can be built, I believe it is very possible. I guess this black and white notation, this checkerboard thing is already a strategy that you don't need computer processing

Participant A4: How about the last question?

Participant A3: It probably doesn't apply to me. The tessellation of the hats (shape), which is an aperiodic tiling so it doesn't repeat. I'm just thinking of quilting(?), it's similar sort of line, that uses squares for particular colours, for the actual design but it's probably something quite different

Participant A4: I can share some of the stuff that came to mind in terms of my own research. I kept thinking about the history of notation and whether non-textual notation is a valid example of notation. I know that in Ghana for example. In the process of weaving Kente cloth. In present day Ghana, there are songs used to not only motivate the act of weaving. But it made me think, is there notation within the rhythm and the musicality of the songs, could that be considered notation because even among basket weaving in certain ethnic groups on the continent of Africa, there are weaving songs. It made me think about that as a notation. Probably because that's where my research sits, in that I'm looking at reframing heritage through a design lens for the sake of cultural continuity. Just thinking about how the methods that designers can use to move from engaging heritage and applying those engagements into current design processes to keep those things alive at different levels. So Ariane's work is really interesting because she's exploring standard notation and thinking about ways that it could continue or evolve with different motivation and because as of my research I'm kind of thinking about that as well, notation historically for weaving, if we can consider songs as notation, because it was probably memorised in the act of weaving, what could that look like for contemporary weaving today?

Participant A3: Are you thinking more in terms of the rhythmic pattern or just actual songs?

Participant A4: Actual songs. Does notation have to be written? Or illustrated to be communicated? Cause she was showing examples of navajo weavers, that it was probably tacit knowledge or maybe transmitted orally. So it got me thinking about how if a song is (...), music is a good way to memorise, I wonder what's in those songs? Is it just rhythm for motivation to keep everybody weaving? Or is there knowledge within the songs?

Participant A1: But also the idea that there could be a relation between the standard western musical notation and weaving notation. I guess I see more relationship to the standard weaving notation as opposed to the void and drawing. But ways that this could relate to my own research I was thinking is obviously fabrics that are mass-produced, having a structure like the standard notation makes sense. But for something more artistic, where the void is maybe more prominent, I'm thinking of the pictorial weaving of Anni Albers for instance where voids are prominent and more (..) You know it's not a functional fabric that she's making, it's more something that needs to be hung on the wall, like an artwork. Then this kind of notation maybe could make more sense.

Participant A4: Back to the purpose of the notation potentially

Participant A1: Yes so I guess if a weaving and an artist who's making a weaving as an artwork, it's not meant to be reproduced necessarily but maybe someone who is looking to preserve in some way (..) might want to record the structure in some way. My dad actually is an Art historian who focuses on oriental carpets and so he is counting warps and wefts. So I think, having an understanding of the void in that context would make sense as well. So it's maybe after textile has already been produced having a different form of notation to record that structure.

Participant A2: I wanted to tell a little bit from my perspective about the void. Actually for me, those X-ray images were very close to what I did in my research, because the idea of digital evaluation is a big part of my work and we would like to estimate the quality of any structure beforehand that it got through the forces or the fatigue that it caused to it. And knowing the void, of these textiles is actually really important. They will test how long they will withstand the forces that they are going through in any structure.

Participant A4: So understanding the void could help see how it could potential extend overtime and destroy the integrity of the woven fabric

Participant A2: These drawings are all very close up reproductions of the void. It makes me wonder if it needs to be that close.

Participant A1: I guess it has to be because the scale of the void is similar to the scale of the thread. But that is a good point. But then for standard weaving notation I understand that you would have a whole weaving thing on a grid that's the size of a sheet of paper. Whereas this the scale would be much larger if you were going to have an equivalent unit for a particular area. Or maybe it's the idea of repetition because you don't need to see more than one unit

Participant A3: Could you have one zoomed in and another one zoomed out

Participant A4: Do you mean the standard or what this could potentially be, what she's exploring. Maybe the question is proximity a factor at all? It sounds like for standard notation, it isn't. Especially with the method that she's using with the X-ray, it's very close up. Seeing it animated in and out of 'existence', that was really clear to me actually than the drawings.

Participant A1: I agree and there's something about, we relate to fabric and textiles all the time. Like we're touching them or interacting with them all the time so to see it in motion is so true to life but I don't how that works in terms of notation for construction purposes

Participant A2: I think when you have those 3D structures, we still are not very sure which are threads is on top or at the back – might be confusing without those in order to identify the pattern.

Group B facilitated by me

Me: So these are just a few questions to get you started. I'm not going to talk too much, and you can start discussing of what you've seen, if you think that the notation that I'm proposing makes any sense? Is there ways that it could be linked to the machine, or not at all? What do you think of using gray in comparison to black and white? How do you feel it relates to your own practice? Or has it changed your perception of weaving, and so forth. So I'll just, I'll just leave you to that.

Participant B4: I mean, I can start with you. For me, it's interesting. My PC was in computer science, so then you have the one zero bit element. So in a sense, my PhD was about pushing that idea and then operating within the logic of the computer. But then it was about, in my case, building a kind of a moral computation that will be kind of in between yes or no, where the machine can reason ethically about something. Then it was about building a multi scalar system in which, in that processing of only one and zero, we could bring some kind of friction or different kind of output out of there. So it's kind of interesting I was playing in the gray area between the clear yes or clear no, and that in between, and then how you can structure that. So I think there's something similar there. But then I think you are in control instead of another agency. Though, for example, in the case of Anne Marie, would be a more than human perspective. How do you bring that extra element, the actual level of agency, which is not human, into the equation? So my case, it might just work more digital in your case will be interesting, whether the material can have an agency

Participant B3: I can go to the next, I think also the greyness is interesting because the greyness is also to me, because I wrote down the synergy that you just said the synergy of networks of empty and full, well you didn't say empty and full directly. But this is what I noticed. But I like that we always think in this black, white and the greyness is interesting because, of course, emptiness is nothing. It's also what you see in your grey drawing: they are never empty and they follow their own way of shaping 'the square'. You see all these bits of curly things happening, you can question if it's agency or not and out of which will is it doing it. But at least it doesn't follow our construct and even this is a very constructed way of organising and the black and white cubes are super structured from us / our perspective but the moment 'it' starts reacting, it has a way of dealing on itself and filling in the grey zone. And, yeah, and I think this is, I like the great drawings, yeah. Also, we've constantly made networks. But what does, what does it mean to. A network, not only with the lines, but with the space in between. So that was a question that

I had, but maybe that's someone else to respond.

Participant B2: It just comes to my mind like a project that became an endeavor of one of my people I did the master with, so they were using microbes and bacteria cellulose to fill in, basically within the structure of the wheel. And that hole well was becoming the structure of the material, because then it was materialized by the bacteria that would be building the space that is in between the holes of the wheel structure.

Participant B4: In a sense, that is what I was trying to say. That is the empty space as a space of possibilities. And then whether your approach, which comes still from a very traditional, let's say, weaving, is limiting the possibilities of that. And then in the moment that you open that space of possibilities, what else can it be there? Whether it can be biological or it can be synthetic, can be smartness, which you are, think at the beginning of your PhD can be emotional, because, I think at the beginning of your PhD then, or whether they can be a more-than-human perspective. So there is a space some of you are in a looking at this space as a quantum space,

Participant B1: I think it is really fascinating and it really comes to mind. I guess with the empty space has, I would say, an equal value or importance as the structure itself. When you weave, then you need that emptiness to support the structure, so I find that relationship quite interesting. You think of the weave as the material that constructs but there is nothingness and emptiness that hold that construction and I think that is really fascinating. I think your way of analysing notation is quite fascinating and how are we looking at microbial or this microbe type of interaction. esterday, I visited the unconventional computing lab here in Bristol, and we were, we were discussing about. So this researcher didn't know why a certain proteinoid was behaving in such a way or was producing the emergence, the way it was replicating. There were questions around that. But the images they were showing, they were a bunch of greyscale, but I would totally see this approach being applied into ways of analysing behaviours at that scale for instance and I think because it relates to, in terms of unconventional computing, like quantum computing, biological computing that is not so binary. I think that this approach of looking at that is really fascinating, that it stems from a weaving tradition.

Participant B2: I'm just thinking of a parallel, as we call non-human and maybe the hole isn't anymore a hole but is something else. Maybe it's also Like, how you frame it, the language.

Participant B4: Building on what [redacted] was saying, in a sense we are pushing our computing into this kind of paradigm. So now we're kind of functioning with biology and then you start to see a different kind of approach and immersion properties. And in a sense it is almost space as a material possibilities and what else can you, I don't know if this will be the future of you PhD or can be a future direction, but when you can say by looking into this it opens possibilities kind of 'beyond', so you can link it to the work of Joseph Albers with colours in which with one colour there is infinite possibilities. And then from there you can build now more as actions rather than (..). I think it's kind of touching into what we are looking. We are working on pushing this kind of idea of the more-than-human, and I think that is the space where design and practice, and then you put this kind of equal positioning, then what you are defining our relationships and possibilities; and we don't know exactly where we're going but that's the way.

Participant B3: I think it's interesting that still your drawings especially the middle one (grey/black/white). Now it's still of course within the drawing you have the greyness of space and material that kind of collide or have synergy and that it's not disconnected but it starts to connect and become almost one but your hand in the drawing, really makes a clear cut in the composition and I find that fascinating actually. That you determine where it stops and where it begins and of course it's because you start with a white A4 . There's really your artistic hand in it and how you can put it all together and I think it really frames something. It becomes a window (..)

Participant B4: There is this artist called Hundertwasser, and I think he's an Austrian artist, and he uses all the time curves. It's very organic and because he says that there are no straight lines and you are moving into that kind of organic , by hand. The thing is whether you can stay in there or you leave a little bit of authorship in that process. Superform module (IDE master): A couple of years ago, we embraced this idea of emerging aesthetics and then you have two paradigms. One is we are going to replicate the processes that we have with a kind of bioplastic (let's say). What we did in this project is embracing the natural properties of the material. So then what you have is an element of the cave and then you have dynamic aesthetic systems. But then you are given part of the authorship by collaborating.

Participant B3: It's really also about authorship. I like the film you made because it's moving and it becomes fluid and it is how somehow you give away some of your authorship to the image itself. With the drawing you are more strict in it. So you have the space, the empty space but of course it's also you. You play a role in that. I don't know, and I think that's also quite tricky with drawing, is that there's always an element of subjectivity that you can't bypass. And I don't know if it's the same in all of your practices, but the idea of using an instrument to represent something or to study something, it does act as an obstacle, as something that alters what you're trying to observe as well. So it also poses this question of, how do you actually study and understand what you are, you know, studying. So actually, that will be quite interesting in terms of understanding. How does that relate to your practice as well? This kind of the tools that you use, you know, I think, in your case, it's the tool or in the pencil and white paper, has also agency.

Participant B4: In my practice I've become more collaborative with other entities. What we are searching is for the supply and I think from 2015, there's a beautiful PhD from goldsmith where they say that we are moving into another paradigm which is ethical aesthetics and that means the only aesthetics is ethics. That means aesthetics in the wider sense as a way of living so then every action, your practice, every action has to be ethics and that's the aesthetic. So the aesthetic is the merger property of that position that you have within the hole. And then we're moving beyond the human centre that was also a very 20th c. modernist approach and when you start to exit that and when you start to collaborate, how do you embrace that. Then all the questions that comes into your practice goes from collaborating with chat GPT to collaborating with a worm and then how do you operate with that. How do you resonate with that (others), because you are working with entities and things…

Participant B1: I'm fascinated with just moving beyond I guess. I mean the way that we collect data through fieldwork but within multispecies sort of lens, fieldwork, how do we challenge the way that we kind of gather that data and looking, analysing that. The way that you are looking at your subject of study is really heavily focused on the sight or you know from a standpoint in that perspective, spatially and temporarily, which already determines how you encounter and will study and analyse, because those are (..) The way that you're notating the weave structure from the tools, the apparatuses being used but the way that you're also breaking that perspective of what we're looking and asking questions of not what is it that we're looking at but the opposite. I think it's kind of like, its an interesting way of notating or observing from completely radically shifting a perspective, in the way that you're using the tools or the drawings. It's I guess affording a type of enquiry. And I guess it's also pointing at the things we are not looking at and that will be our limitation of how we sense the world around us. Because we are just limited to our senses but then I guess that will always be limited by what could be augmented by certain technologies but still, we will have limitations, we will never know what it feels to feel certain sensations and like in certain parts of our body. My point is that this sort of way of notating, I guess, challenges how we read or understand. For me it's more around the methods of how we collect or interpret or analyse or change perspectives in what we study.

Participant B3: It also relates to what you started with to have this black/white cubes kind of notation. It is about communicating to whom or for what purpose and then because you need a way of communicating for a lot of workers and before it was in your hands. This knowledge, this black/white cubes was not black/white cubes on a piece of paper but it was just in your hands, your body. I think this is interesting this shift, which of course relates to for who do you make for and that also relates to my practice in the sense that you start materialising invisible dust, air pollution and data — for whom, who's the audience, the public. And a lot of time these projects are framed as awareness campaigns. But awareness is the same with agency, with what purpose or with what, for which policies. Do we need to change our own behaviours as individuals, is that the message? Or at what kind of systematics do you need to kind of start pushing all the buttons – for me that is also the question of agency. For whom, for what and how the artefact is part of that communication and discussion?

Participant B2: Looking at my practice and i'm currently doing a lot of studies with mapping and the outcome are these very busy and messy maps and I'm looking at the map from the part that is visualised but building on what [redacted] was saying, maybe I should also look at what is not visualised. A framework to see maps, eventually.

Participant B4: One part of my research recently on one side was kind of formalising all this interaction. When you bring knowledge from different entities, do they operate symmetrically or asymmetrically? Because the moment that we have this asymmetric, we have more weight than the rest. If it's symmetric then how do you make decisions? How do you integrate knowledge coming from different elements? We need to build almost another vocabulary to start to define this (…) we have a paper called the polygenetic designer (...). The second is who are we designing for ? The last paper we published – something called counterism, there is an evolution in the function of the critical. With a critical movement from and end to be a mean and design became from critical to tactical. Here we were designing on behalf of (hopefully) the planet and then at the moment that we have that position, the object in itself or the exhibition is not enough. We need another loop in which you start to target let's say illegal systems in which you can effect change. In that conference there were a lot of more than humans. It was all about how we can communicate with plants, with animals (...), how we can listen fundamentally was the idea and bring them into the table. Once they are in there, how we can give them the same level or status and how they can influence or affect policy and change. In a sense all these elements are aligned. And i was really surprised of how well-accepted was that paradigm because there was a lot of scepticism when you were moving beyond the human-centred paradigm.

Me: [redacted] you were working with the idea of having conversation with bacteria, what are your thoughts on this?

Participant B1: Yes back in 2021, that study was left unfinished and I was really very naive – because I wanted to do ethnographic studies in a lab setting with a more than human paradigm so I was looking into multi species research and I was thinking well, if I conducting interviews with people, then I should also conduct interviews with their collaborators in the context of co-design, a lot of designer call their bacteria collaborators. And I was sort of sceptical in all honesty about that framing of collaboration, because in a bio-design lab context, ultimately you sterilise a bacteria, you kill it, you use it for purposes of production, in order to make a final piece of work. I was starting with my assumption about that so as if I was trying to prove that. And then I think in that sense when I was doing that field research, in the lab, I was already like, of course you cannot talk to a bacteria and expect that. I was literally sitting in the lab, listening to the whole machinery of the lab and I was very intrigued about the affordances of the space – the lab settings, the gloves, the glasses, everything was just far removed from my bacteria. I was not being in touch - and I had to actively kill it to produce a tiny amount of pigment, and I was like 'hey collaborator', you're the corpse here. But I think for me that experience really highlighted how it is not that easy to approach a research i guess, traditional research method such as ethnography with multi-species paradigm. I was doing a direct translation there – I'm going to do an interview in this way. So then I was very intrigued what other approaches and I was looking into more sound research and specifically the work of Paoline Oliveros, for deep listening practices, more for composing and sound research. But there was actually very interesting insight from practice as listening because it engages a lot to embodied knowledge practices, I think it is also related to the silence that dust (...), because sound is a form of dust and noise and absence and there is never a pure silence. I mean it's fascinating how that could be notated into sounds. I guess it is related to multi-species context in a sense that there are a lot of frequencies that we are not attuned to because of our capacities as humans. And the only way we can attune to those will be through this (...). I mean right now technology is being used for that, for translation, representation that's also really super complex. Humans will also represent and that process of representation especially in board of directors, constitutions, the act of representing will already always be humanly done, it will be (...). So representing is something I am quite not so sure about. But what would be the best way to represent. And I'm not sure that representation is always the best representation. But different modalities of interacting, observing, understanding could maybe lead to new possibilities. So I think it is exciting how we are challenging the way that we are studying and researching the very methods and tools and ways of observing, listening.

Participant B4: In a sense you realise that you need a different epistemology, but you need an ontology (..) That ground which the symmetry, the affordances of sounds, then you can build. The problem that we have in design, in the past we defined epistemology without defining ontology and then we brought different models. But then, they have a different logic so then we have this struggle at the end and try to justify what was the role of design, because we were using psychology. Understanding that is kind of, the attempt that we did was to try to build that ontology where we gonna start to build (...). But it's interesting connecting to Ariane is this idea of the silence. The negative space but then what the research is showing is that we need stop thinking about this space as such and more thinking about active space rather than negative space. And I think that can be the transformation where you can start to build all these elements. It's a space for listening, for a lot of things. It is the framing of the negative, removing this idea of a passive element that is becoming active.

Participant B3: The representation is interesting. How the weaver starts weaving before, they just had it in their hands. Also in a way they preserved the knowledge but in your way of emptiness. It's never officially written down so it's always in the hand. It's a way of preserving the metaphor of emptiness. The moment you start drawing, making, immediately (...) How do you recognise or how do you deal with communicating with everything that is in your hands?

.... end of discussion groups meet ....

Participant A1: Your notation: it would be easier to record the structure of an existing fabric potentially. Whereas the other notation system would be easier for someone who's going to weave something new from scratch

Participant A3: Grey weaves were too ambiguous and reminding us of X-rays.

Participant A4: If you have expert medical knowledge, you can spot a shadow on an X-ray. As opposed to just sitting there, you don't really understand the nuances between the greys that you're seeing. Grey carries a lot of nuance. Especially in this sketched form rather than a block of grey, I don't know. I think we all had the same (..) The grey was harder to grasp.

Participant B4: I think it's kind of building from what they said, we focused on that ambiguous space as a space of possibilities

Participant B2: Have you tried to play with the colours? Because I think it's very different (..) so grey, the scale of grey is often connected to emptiness, what about if you use other colours.

Participant B2: Yes but somehow grey and red they can mean nothing. Think about colour blind. Can you put aside the meaning of the colour? Because if you're using grey, you could use red.

Me: But doesn't that just pauses the same issue in that shades of red become just a blur. I think it's really interesting that you feel like adding an element, colour, would render the visualisation more communicative.

Participant A3: What about alpha numerics? I create these cellular automata cave-like mazes. The background might be a dot, the foreground might be another sign and another one might be another sign. Then it doesn't use colours but uses signs.

Participant B1: The parameters are quite (..) like if it's just colour, then we're looking at colour. But colour can have so many different textures, and specifically in a grey context. There is grain and noise and if we were to add that complexity to the greyness it would communicate a lot more.

Participant B3: To me it's also a case of do you want to read the image? To me there's two different questions. One is reading it and understanding greyness, emptiness, the synergy between them or the other question is how do you communicate the emptiness for weavers and using the same methods and ways of representations. That's communication, that's output. These are two different discussions. You communicate to weavers about emptiness (to make it flat) then you might use colour, then you can use communication tools or shapes (…) But for the reading, colour is super complex

Participant A4: Using notation that captures the void to see how a material weakens over time because the void would become bigger and bigger.

Participant A2: We are working with the material structure and collecting the greyscale or if you want you can colour these images and you can find the anomaly from what you expect. In the context of what Ariane showed us today, I think the contrast, using the empty space, was actually very strong and I really like that. Because it was very difficult for me to identify with the white background and just threads vs the black background and the white threads. I think that contrast what much more strong and the X-ray images are really important because yes I can take those images and try to investigate fabrics.

Participant A4: Does notation have to be written in order to be a notation? Songs are merely rhythmic motivation to keep everyone keep weaving. But it got me thinking about knowledge being passed down through verbal communication. And even the implication of accessibility, opening up creating weaving patterns for non-sighted people. High tone / low tone has a form of notation. What notation is and could be? If it's about communication, could song be a form of notation? Does it only start when things are being written down? How could weavers today create notations that still reflect that same heritage? I think it opens up opportunities for synthesis, looking at heritage, industrial methods to keep that heritage alive so that it doens't just become a product of history.

Participant A1: Paul Klee was a musician. The earliest abstract artists including Kandinski who was his colleague and friend kind of used music as a justification or a model for abstract art. So there's so many parallels between art, more visual things and music.

.... end of discussion ....

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