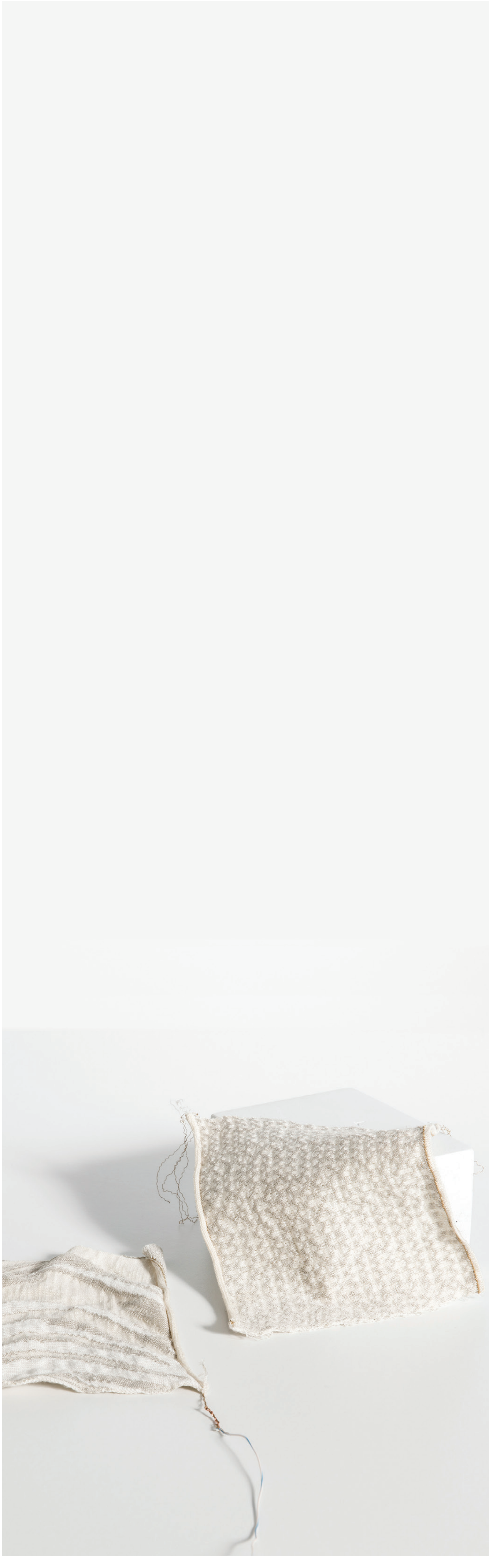
Digital Dynamics: An Interactive Design Process for Generating Knitted Textiles



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Abstract

This practice-led research project investigates new generative ways of designing with interactive textiles, embracing their inherent active and temporal properties to develop alternative methods and open up new aesthetic possibilities. In this project interactive textiles are recognised as constructed material artefacts and their expressive, performative behaviours are used to inform new ways of making. The investigation opens up a new design space for textiles through a deeper understanding and utilisation of interactive textiles and their behaviours through new forms of digital making with materials.

Due to their temporality, these materials are regarded as collaborating agents. This allows for a design process of interaction and collaboration with active materials and self-assembling matter. By refracting and disrupting conventional linear textile and knit design processes new methods for transforming interactive knit structures emerge. Interactive textiles are explored through an evolving, generative textile design practice. In the context of matter and technology as materials for design, a generative process that allows for a decoding of digital information to generate new forms is adopted. Through this process textiles simultaneously become both tools and materials to design with; the function of the textile - in its digital or physical state - is to inform the making of new interactive textiles.

The significance of this research lies in its methodological contribution to contemporary textile design practice through the formulation of new generative textile design methods. The research and practice embrace digital and physical materials; recognising the particular procedural and aesthetic qualities of these new media.

Table of Contents

List of Figures iv
Attestation of Authorship vi
Acknowledgements vii

Chapter 1. Introduction 1
1.1 Positioning the Researcher 2
1.2 Research Introduction 2

Chapter 2. Contextual/Conceptual Framing 4
2.1 The Meaningful Matter of Textiles 4
2.2 Seeking Paths of Divergence: Textile Design Processes 5
2.3 The Meaningful Matter of Digital Technology 6
2.4 Analysis of Digital Making 6
2.5 Intertwining Textile and Digital Matter: Interactive Structure and Surface 8
2.6 Exploring new Modes of Making, Intertwining Textile and Digital Matter 8
2.7 Toward a new Mode of Making, with Textile and Digital Matter 10

Chapter 3. All Material Matter 11
3.1 Digital Textiles, Questioning Perceptions of Materiality 13
3.2 Digital Matter 13
3.3 Matter Assembling/Collaborating Agents 13

Chapter 4. Informing Methodologies 16
4.1 Practice-led Research 17
4.2 Experimental Research Through Design and For Design 17
4.3 Interactive Design Methodologies 17
4.4 Generative Systems 18
4.5 Craft Practice Informing Digital Knitting 18

Chapter 5. An Intertwined Process 19
5.1 Introduction 20
5.2 Expressive Components: Conductive Stitch Structures 20
5.3 Embodied Making: Collecting Data 21
5.4 Generative Structures 21
5.5 Digital Knitting: Rhizomatic Approaches 26
5.6 Digital Matter Moving through Material States: Reactivating Knit Structures 26
5.7 Collecting Digital Knitting Data as Material to Design With 30
5.8 Crafting Digital Data 30
5.9 Matter/Material Qualities 34
5.10 Collaborating of Bodies and Forces 38
5.11 The Materialising of Generative Textiles 40
5.12 Exhibiting Expressive Materials, Generative Textiles and Digital Matter 45

Chapter 6. Conclusion 46

References 49

Appendices 53
Appendix A 54
Appendix B 61
Appendix C 81

List of Figures

Figure 1. Stephen, C. (2016). *Studio Space.* [Digital Image].

Figure 2. Stephen, C. (2016). *Studio Space Detail.* [Digital Image].

Figure 3. Stephen, C. (2016). *Interpretation of Lawson's 2005 Design Model.* [Digital Image].

Figure 4. Studd, R. (2002). *Generic Framework for Textile Design (p. 42).* The Textile Design Process. The Design Journal, 5(1).

Figure 5. Crabtree, Evans. (2014). *Antonio Bay (p. 126)*. Postdigital Artisans (2015).

Figure 6. Unfold Studio. (2012). *Stratigraphic Manufactury (p.235).* Digital Handmade (2015).

Figure 7. Persson, A., Bondesson, A., Worbin, L., (2009). *Textile Dimensions: An Expressive Textile Interface (p.55).* Exploring Textiles as Materials for Interaction Design*(2013).*

Figure 8. Stephen, C. (2016). *Dialectical Framing.* [Digital Diagram].

Figure 9. Stephen, C. (2016). *Digital Scan of Concept Board.* [Digital Image].

Figure 10. Marks, S. (2016). *Photograph of 3D Digital Textile.* [Digital Image].

Figure 11. Stephen, C. (2016). *Digital Scan of Textile.* [Digital Image].

Figure 12. Stephen, C. (2016). *Expanded Dialectical Framing.* [Digital Diagram].

Figure 13. Barber, M. (2016). *Sculpture Knitted Textile 14.* [Digital Image].

Figure 14. Stephen, C. (2016). *Textile/Arduino Capturing Interaction.* [Digital Image].

Figure 15. Stephen, C. (2016). *Grasshopper/Rhino Interface.* [Digital Image].

Figure 16. Barber, M. (2016). *Iterative process/Artefacts emerge.* [Digital Image].

Figure 17. Barber, M. (2016). *Conductive Knit Structures, Data Sculptures.* [Digital Image].

Figure 18. Stephen, C. (2016). *Rhino Rendering of Data Sculptures.* [Digital Image].

Figure 19. Barber, M. (2016). *Data Sculptures.* [Digital Image].

Figure 20. Stephen, C. (2016). *Converting to Knit Structures in Shima Seiki SDS-ONE system*. [Digital Image].

Figure 21. Stephen, C. (2016). *Scan/JPEG/Knit Simulation Mapping* .[Digital Image].

Figure 22. Stephen, C. (2016). *Shima Seiki Notation for Knit.* [Digital Image].

Figure 23. Stephen, C. (2016). *Collecting Shima Seiki development data.* [Digital Image].

Figure 24. Barber, M. (2016). *Data Sculpture Knit 15, and Data File Knit 16.* [Digital Image].

Figure 25. Barber, M. (2016). *Data Sculpture Knits 1-6, and Data File Knit 7.* [Digital Image].

Figure 26. Stephen, C. (2016). *Condensing Shima Knit Data* [Digital Image].

Figure 27. Stephen, C. (2016). *Data File Knit 20.* [Digital Image].

Figure 28. Barber, M. (2016). *Data Sculpture Knits 14 and Data File Knit 20.* [Digital Image].

Figure 29. Stephen, C. (2016). *Documentation in Journals.* [Digital Image].

Figure 30. Barber, M. (2016). *Data Sculpture Knits 11 Pemotex/Wool/Silk and Stainless Steel Reaction to Heat.* [Digital Image].

Figure 31. Stephen, C. (2016). *Work Space* [Digital Image].

Figure 32. Stephen, C. (2016). *Concept Board: Layering Surfaces, Moving Materiality.* [Digital Image].

Figure 33. Barber, M. (2016). *Tangible Interactions.* [Digital Image].

Figure 34. Barber, M. (2016). *Data Knit Structures Become Tools for Further Generation.* [Digital Image].

Figure 35. Barber, M. (2016). *Tangible Interactions.* [Digital Image].

Figure 36. Marks, S. (2016). *Yarn Selection.* [Digital Image].

Figure 37. Stephen, C. (2016). *Large Scale Data Cast Jaquard No 1.* [Digital Image].

Figure 38. Stephen, C. (2016). *Detail of Large Scale Data Cast Jaquard No 1.* [Digital Image].

Figure 39. Stephen, C. (2016). *Detail of Knit Data Jaquard No 2.* [Digital Image].

Figure 40. Stephen, C. (2016). *Detail of Knit Data Jaquard No 4.* [Digital Image].

Figure 41. Marks, S. (2016). *Data Cast No 2, Knit Data No 4, Data Cast No 1 and Knit Data No 1.* [Digital Image].

Figure 42. Marks, S. (2016). *Knit Data No 1, Knit Data No 2, Knit Data No 5, Data Cast No 2.* [Digital Image].

Figure 43. Marks, S. (2016). *Conductive Data Casts connected to Arduino.* [Digital Image].

Figure 44. Marks, S. (2016). *Close up of Knit Data No 2, Knit Data No 5.* [Digital Image].

Figure 45. Marks, S. (2016). *Large Scale Jaquards in Exhibition.* [Digital Image].

Figure 46. Marks, S. (2016). *Detail of Large Scale Jaquards in Exhibition.* [Digital Image].

Figure 47. Marks, S. (2016). *Detail of screen and sensors Interactive Installation in Exhibition.* [Digital Image].

Figure 48. Stephen, C. (2016).*Detail of Knit Data Trial.* [Digital Image].

Figure 49. Marks, S. (2016). *Detail of programming for Interactive Installation in Exhibition.* [Digital Image].

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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Fig 1. *Studio Space.*

Chapter 1. Introduction

1.1 Positioning the Researcher

I come from a family of makers. While vaired in practice - textiles, timber, ceramics - their individual processes of crafting has infuenced my approach to making and materials.

I hold an undergraduate degree in both Spatial and Textile design and I am inherently interested in the spaces between textile design, craft knowledge and material futures.

For my undergraduate project in Textile Design I created a collection of knit wear garments; the body of work was speculative investigation into future materiality and new modes of craft. This research, in a lot of ways, commences and unfolds from where my undergraduate project concluded.

1.2 Research Introduction

This inquiry explores interactive textiles as constructed material artefacts and investigates their potential as generative design materials for the development of new textile design methodologies. Using traditional materials and combining them with advanced conductive materials and technology, the aim of this research is to generate alternative methods and open up aesthetic possibilities with these materials. Through investigating forms of digital making with materials, this research opens up a new design space for textiles through a deeper understanding of interactive textiles and their behaviours.

The development of interactive, smart and electronic textiles have thus far been focused on technical applications within military, medical or industrial sectors. This research is not to add to these areas but to propose a generative process in crafting interactive textiles. New materials have the potential to expand textile design spaces but "designers must re-think not just form and aesthetics, use and function, but how to go about designing in such a new and complex situation. Design – and designing – thus become a critical site for research and redefinition" (Redströem, Mazé, & Redströem, 2005, p. 31).

The structure of this thesis, the research and design outputs all draw from philosopher Manuel DeLanda's (2006) notion of fluid assemblage. DeLanda's assemblage is defined by two axes and is composed of material and expressive components that move between stabilised and destabilised states.

The design outputs in this research have been developed through experimentation mapped along two intersecting axes. The vertical axis in the research involves forms of digital and physical materiality as fundamental textile components; the horizontal axis plots the making and the emergence of artefacts. This infrastructure of two axes creates a framework for the design practice, while philosophical and material questioning drive the research. Theoretical and practical components assemble and intermingle within the axes establishing a dynamic, contingent and emerging practice to generate both designed artefacts and tools for formulating knowledge around new modes of making interactive textiles.

This research seeks to find a new way of designing with interactive textiles, embracing their inherent active, temporal properties. Through the practice of making with temporal design material, the materials in this research are regarded as collaborating agents (Cooper, 2014, p. 194), and are considered as active contributors to the creative process. In this design proposal, generative practices are employed in the research as a way of interacting and collaborating with active materials and self-assembling matter (DeLanda, 2001; Massumi, 1992). The textile practice explores methods for transforming interactive knit structures through an evolving, generative approach that refracts and disrupts conventional linear textile and knit design processes. When a disruption or divergence takes place, the destabilisation in a design process allows for new modes of making to emerge. In the context of matter and technology as materials for design, a generative process here allows for a decoding of digital information to generate new forms. In this research textiles simultaneously become both tools and materials to design with, the function of the textile (digital or physical) is to inform the making of new interactive textiles. The expressive, performative behaviours of interactive textiles are used to inform new ways of making.

This exegesis, like the design practice established, is presented in a non-linear form, diverging from conventional methods, where digital images and text run into each other on the page. The exegesis should be understood as an assemblage of ideas and concepts, active and shifting, interrelated to the artefacts that emerge through the proposed practice.

The critical focus of this inquiry is the questioning of how the development of textiles might be challenged through the adoption of new methods that recognise and utilise the particular procedural and aesthetic qualities of these new media.
Through the course of this inquiry, sub-questions have emerged: How do we design to embrace the shifting fluid qualities of these new materials? How can a design process embrace interactive textiles as collaborative agents?

The contribution made by this research lies in its methodological contribution to contemporary textile design practice through the formulation of new generative textile design methods that embrace digital and physical materials.

Chapter 2. Contextual/Conceptual Framing

2.1 The Meaningful Matter of Textiles

Textiles are the immersive soft structures and surfaces we move in and through everyday. Textiles are materialised as cloth and fabrics for clothing our bodies, as our belongings, and in our environments. There is a complexity inherent in textile structures, described by Pajaczkowska, as material systems where "matter is inextricably imbued with meaning" (2010 p.139). Following from this notion of meaningful matter, textiles can be regarded as surfaces embedded with cultural and historical significance. Their material properties and structural changes become narratives - tangible manifestations of culture, time and memory. Fundamentally, textiles can be understood as materials created by the interlacing or interlocking of fibers. These structured networks of fibres are produced through specific technical processes, including but not limited to, knitting, weaving, felting and braiding. This project engages with the process of digital knitting as the primary mode of making.

Fig 2. *Studio Space Detail.*

2.2 Seeking Paths of Divergence: Textile Design Processes

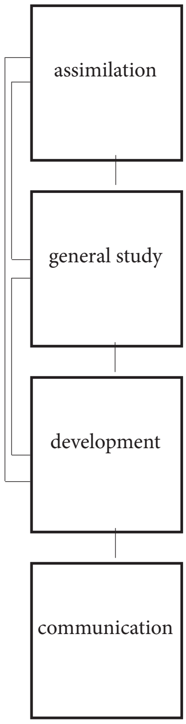

Fig 3. *Interpretation of Lawson's 2005 Design Model* (2016)

The textile design process is multifaceted as it encompasses the design of the structure of a textile through to surface decoration and in some cases (like knit design) the final product or garment. Surface design involves practices such as woven or print design, while knitwear design conventionally involves the design of the knitted textile and the garment in one process. The final physical properties of any textile, including its appearance, functional and tactile qualities, depend on its specification for use in apparel, interior or technical textiles (Bang 2010, Horrocks & Anand 2000).

At the most fundamental level, a textile designer's practice involves working within practical, aesthetic and economical parameters to "design and produce [...] commercially viable fabric designs" (Wilson, 2001, p.18). Knitwear design processes in industry commonly begin in a similar manner, with textile swatch development but can also extend to final application or garment design (Taylor & Townsend, 2014). In the wider practice of design Lawson (2005) visualises a structured approach with a linear flow of work, where iterative process are employed to work towards a determined final outcome. The diagram to the left demonstrates Lawson's linear design process.

Most textile design processes outlined in key textbooks follow a similar linear flow. In *Handbook of Textile Design* (2001) the textile design process is described by Wilson as following five key phases or steps: need, research, idea generation, design development and finished design. Studd (2002) illustrates an overview of the textile design process within its industry contexts. Studd also identifies five stages consisting of planning, research and analysis, synthesis, selection and, finally, production. Expanding on Wilson's streamlined model Studd unpacks each stage as having a series of smaller stages nested within. These textile design models show that the design process is seen to move through phases in a linear manner where an end goal is established at the beginning of the design process and necessary steps are taken to achieve this.

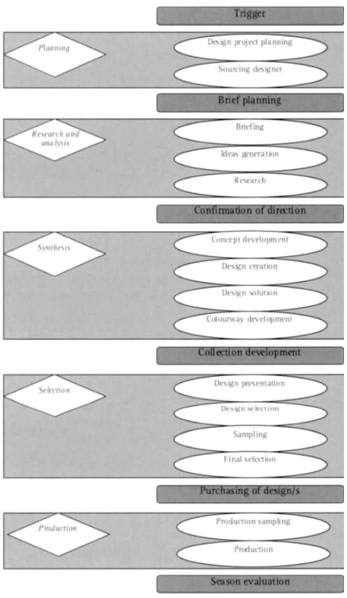

Fig 4. *Generic Framework for Textile Design. p. 42* (Studd, 2002).

In design practice research is an important aspect of the design process, and one that is included in all of the above examples. Research is a fundamental step in generating new designs but the methods and degree in which such 'research' is carried out varies within organisations. According to Roth (1999), there are key differences in design research within industry and academic contexts. Design research in industry is always related to a particular project and executed within a commercial time frame. Methods employed can include social and behavioural sciences, as well as marketing and business analyses strategies. The research developed is proprietary. On the other hand, design research conducted in an academic context can expand research scope, is inclusive of an extensive range of methods and approaches and the information produced is regarded as a contribution to knowledge (Roth, 1999). Within commercial textile design, market research can include a consideration of specific areas such as trend analysis and other forms of fashion forecasting. This investigation into new design methods with interactive textiles embraces these allowances in an academic setting. The research component of the practice-led work extends between textile and interaction design, allowing for philosophical trajectories to emerge between physical and digital materiality and modes of making.

2.3 The Meaningful Matter of Digital Technology

Technology, like the immersive textile, has a pervasive disposition. While we live our lives with and through technical objects (Kroes, 2012) technology is always shifting, evolving and advancing. We now exist in a time often referred to as the third industrial revolution (Kuchler, 2008), an age defined by digital advancements in technology, the ubiquitous role of computing and software. In this existence we continuously reformulate our being in the world as screens, interfaces and networks continue to infiltrate everywhere (Openshaw, 2015).

This infiltration of computational systems into everyday artefacts has brought about "intensified interest in 'thingness' and materiality" (Svabo, 2007, n.p.). Notions of digital materiality and digital artefacts are being examined in an attempt to redefine the material in the absence of physical matter (Leonardi, 2010; Casemajor, 2015). Robles and Wiberg describe digital technologies as textured, becoming "part of the materials that surrounds us and constitute our built environments" (2010 p. 139). Vallagård and Redström (2007) place information technology as an entity existing in between the material and the immaterial, pliable in nature and able to be molded in different forms. Manovich (2001) and Kallinikos and Mariategui (2011) consider digital artefacts such as files and images as fluid and adaptable being embedded within complex and shifting digital environments.

This research explores these notions of digital materiality and computational matter as 'materials' and 'tools' for generating new modes of making interactive textiles. It examines how digital artefacts can be interpreted, formed and applied to "design *from* it, *with* it and *for* it", to use the words of Hansen and Morrison (2014 p. 33).

2.4 Analysis of Digital Making

Technology, as it seeps in and around us, alters and expands our understanding and notion of materiality, tangibility, the digital and the physical. Furthermore, this has led to the fundamental rethinking of art and design and expanded methods, forms and purposes. In *Postdigital Artisans: Craftsmanship with a New Aesthetic in Fashion, Art, Design and Architecture*, Openshaw describes how the digital has become a prevalent force in how we interact with our surroundings. Designers are increasingly seeking methods of making "with new expectations of malleable form, responsive surfaces and connected behaviour" (Openshaw, 2015 p. 8). Digital infiltration, with its screens, interfaces and networks, is reformulating methods of making across all domains in art and design.

The following design practices explore materials and materiality at the intersection of craft and digital processes. While neither of theses practices is involved in textiles, they both investigate modes of making that inform this research. Crabtree and Evans create sculptural installations and work with materials such as polystyrene foam, plaster, rubber and digital files. They situate their work between digital and physical realms, creating feedback loops in practice to inform further making. "We're interested in what happens to objects and images when they are moved between real and virtual spaces and how our perception and understanding of them shift. How an object can be an image, and how inanimate objects can perform," states Crabtree (as cited in Openshaw, 2015, p. 127). Their practice involves creating digital models of spaces, then alter the models with temporal digital mediums such as CGI smoke. Images of the spaces

are then digitally printed onto unconventional tactile materials such as carpet to explore what occurs when digitised modes of viewing become rendered into physical things.
In another medium again, Design Studio *Unfold* examine how three-dimensional objects generated from identical digital files change in reproduction depending on artist and material, innovating interventions within craft processes (Johnston, 2015). 3D printing is explored as a craft practice as data files are sent to ceramic artists who then interpret the files into porcelain objects using open-source 3D printers. The hand of the digital maker is evident and embraced in the idiosyncrasies and flaws of the final artefact.

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Fig 5. Crabtree & Evans, *Antonio Bay*. Image from Postdigital Artisans. *p. 126*. (2015)

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Fig 6. Unfold Studio, *Stratigraphic Manufactury*. Image from Digital Handmade *p.235*. (2015).

At the site of this research, new technology allows for practice at the intersection of textile design and digital making, engaging with emerging textile practices in digital craft and technical making. The development of these new materials requires new methods of textile design. The old linear commercial textile design models proposed by Studd (2002) and Wilson (2001) are inadequate in addressing these new conceptual and technological dimensions of textile design.

The inquiry sits within a context of questions raised by this ontological reframing: What happens when these digital components manifest in the textile surfaces that encase our everyday experience of the world? How is technology changing the face of textiles? This research explores these questions through a design driven practice. Pivotal questioning in this investigation involves exploring how we can activate new ways to develop textiles, embracing new methods that can recognise and utilise the particular procedural and aesthetic qualities of this new medium.

2.5 Intertwining Textile and Digital Matter: Interactive Structure and Surface

Digital materials and computational systems are having an enormous impact, not only on the design but also the making and assembly of everyday objects. New materials and electronic components are embedded into multiple surfaces and structures within our environment, and emerging technologies are transforming textile surfaces from analogue cloth to digital fabrics. These digital fabrics enriched by technology with their electronic yarns and computational components are known as interactive, electronic or smart textiles.

Interactive textiles are described as materials and structures ingrained with the ability to sense and react to environmental stimuli through mechanical, thermal, chemical, electrical, magnetic or other sources (Tao, 2001). They are classified into one of three categories according to their electronic properties: passive smart, active smart and very smart materials. Passive smart textiles can sense environmental conditions or stimuli, active smart textiles sense and react to the stimuli and very smart textiles have the capability to sense, react and adapt themselves to environmental conditions or stimuli (Tao, 2001; Stoppa & Chiolerio, 2014). Smart textiles, therefore, can be defined as physical materials with reactive behaviours, materials that are "augmented with the power of change and have the ability to perform or respond" (Verbücken, 2003 p. 54). This ability to perform and respond adds a new communicative capacity, transcending that of analogue materials with their inherent cultural and historical meanings. New material systems are becoming "carriers of knowledge, capable of impacting on us directly in an open-ended sensory manner" (Küchler, 2008 p. 103).

Interactive textiles as intricate material systems are where matter materialises physically and digitally - where atoms and bits intertwine (Ishii & Ullmer, 1997; Wiberg & Robles, 2010). They are understood as unstable (Ramsgard Thomsen & Bech, 2012), fluid (Dunne, 2005), continuously in movement (Bergström et al., 2010), with "complex and variable behaviours" (De Landa, 2004, para. 15). Because of these moving, complex behaviours Bergström et al. express the need to understand interactive textiles as 'becoming materials', materials that "come to be, or become, only over time and in context" (2010, p.155). This research investigates the potentials of using these unstable, fluid, becoming materials to create a new design process, one that designs with the complexities of shifting materialities to generate new textile systems, structures and surfaces.

2.6 Exploring new Modes of Making, Intertwining Textile and Digital Matter

The development of interactive, smart or electronic textile structures has primarily focused on applications within military, medical or industrial sectors. Redströem notes that while there is a vast amount of research conducted on the technical possibilities of new textiles, "the creation of materials with the ability to sense, react and change points towards a future of uses, expressions and design possibilities not previously associated with textiles" (2005, p. 8). Opportunities to embrace interactive textiles as expressive materials for design have been overlooked and designers need to re-examine textiles and computational technology on account of a complex melding of traditions, perspectives, concepts, methods and materials. Bergström et al (2010) further argue that as new materials are developed designers must formulate new ways of conceptualising, describing and working with materials in design. Interactive textiles, with their innate ability to react and respond, reveal new design spaces for textile expressions and forms. However, as mentioned, interactive textiles also bring about design challenges, demanding for expanded approaches on how to design for interaction (Vallgårda & Redström, 2007; Ishii et al., 2012; Minuto & Nijholt, 2013).

The following research project explores textiles as materials for interaction design with intentions of expanding the computational textile design space by focusing on the dynamic elements of interactive textiles. In *Exploring Textiles as Materials for Interaction Design* (2013) Perrson examines various visual and tactile interactive properties of primarily knitted textiles. She reiterates ideas established by Vallgårda and Redström by stating "the shift in focus towards a materiality of computation demands alternative approaches towards new design methods and ways of thinking when designing computational things" (2013, p. 10). Perrson develops a theoretical framework that establishes alternative approaches and ways of thinking by adapting methods from both interaction design and textile design and by contextualizing the temporal materiality of interactive textile materials. *Textile Dimensions: Expressive Textile Interface* (fig. 7) a collaborative design project between Persson, Bondesson and Worbin, is an example of an expressive textile interface where the user's physical participation affects a visual change; the textiles explore the possibility of extending their properties through interaction. Temporal materiality explored here can be understood as "both the material attribute of changeability within a given context and the continuous negotiation of the material expression directly or indirectly with the contextual factors in which it comes to be" (Bergström et al., 2010, p.158). This research and its findings engage in what Dunne (2005) describes as a need to expand notions of design aesthetics to look at poetic and metaphysical relationships with technological artefacts.

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Fig 7. Persson, A., Bondesson, A., Worbin, L., *Textile Dimensions: An Expressive Textile Interface* (2009).

In this research and body of work the practice of designing with and for expressive and interactive materials not only expands ways of thinking about textiles but also opens up dialogue around new methods of making, revealing new research paradigms, processes and conceptual outcomes.

2.7 Toward a new Modes of Making, Intertwining Textile and Digital Matter

How do we design to embrace these shifting fluid restless materials?
How can a design process be set up to embrace interactive textiles as collaborative agents?

This practice-led research proposes new processes of designing, opening up the design space for creating interactive knit structures by drawing on methods of making that sit outside of traditional textile design practices. In establishing new processes, this practice engages in the potential of making with 'fluid', 'becoming' textiles as generative design materials, thus readdressing structure, materiality and interactive behaviour in textile design.

The aim of this research was not to develop commercially viable fabrics but to turn methods of making textiles inside out and explore the potential of interactive textiles become collaborating agents for generating new knitted textile artefacts. With no singular defined outcome intended, this research embraced an open-ended, explorative and generative mode of making. A dialectical framework maps out the site of investigation; based on two intersecting axes the intention is to disrupt and refract conventional linear textile and knit design processes to explore new ways of making with interactive materials.

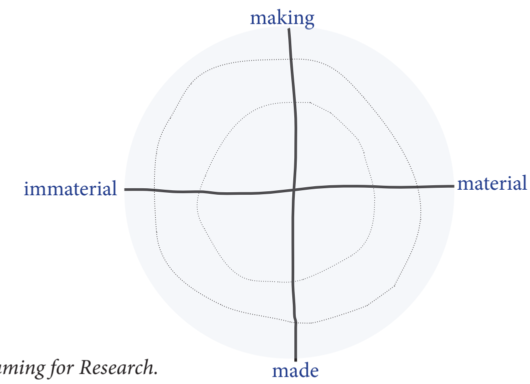


Fig 8. *Dialectical Framing for Research.*

Here the notion of the 'dialectical' draws on theories put forward by Walter Benjamin (Buck-Morss, 1989) and Manuel DeLanda (2006) to allow for new ways of seeing and thinking through concepts and processes. The dialectical image which Benjamin proposes is a mapping of an assembly of fragments or constellation of ideas. In Benjamin's *Arcades Project* (1927-1940) he charts philosophical theories visually within two intersecting axes as a way of seeing antithetical, but connected elements - elements that are only in existence due to the other (Buck-Morss, 1989; Pensky, n.d). DeLanda, too, proposes a dialectical framework in his work *A New Philosophy of Society. Assemblage Theory and Social Complexity* (2006). As he expands upon Deleuze's assemblage theory, DeLanda suggests a collection of components organised, in a non-linear manner, through two axes. A material/expressive axis and a territorializing/deterritorializing axis creates the framework, allowing for DeLanda's theories to be plotted and processes in which a component is involved are mapped. A third axis defines interventions involved in the coding, decoding, and recoding (DeLanda, 2006) of the assemblage.

The vertical axis in this research includes digital materiality and physical materials as fundamental textile components, while the horizontal axis plots the making and the emergence of interactive knit structures. Through an assemblage of elements mapped across the proposed axes, this framework allows for an evolving and generative approach, the design process unfolding through encounters and emergence in making. A philosophical and material questioning drives the research, while the practice-led components generate both designed artefacts and tools for formulating knowledge around generative textile methodologies.

Chapter 3. All Material Matter

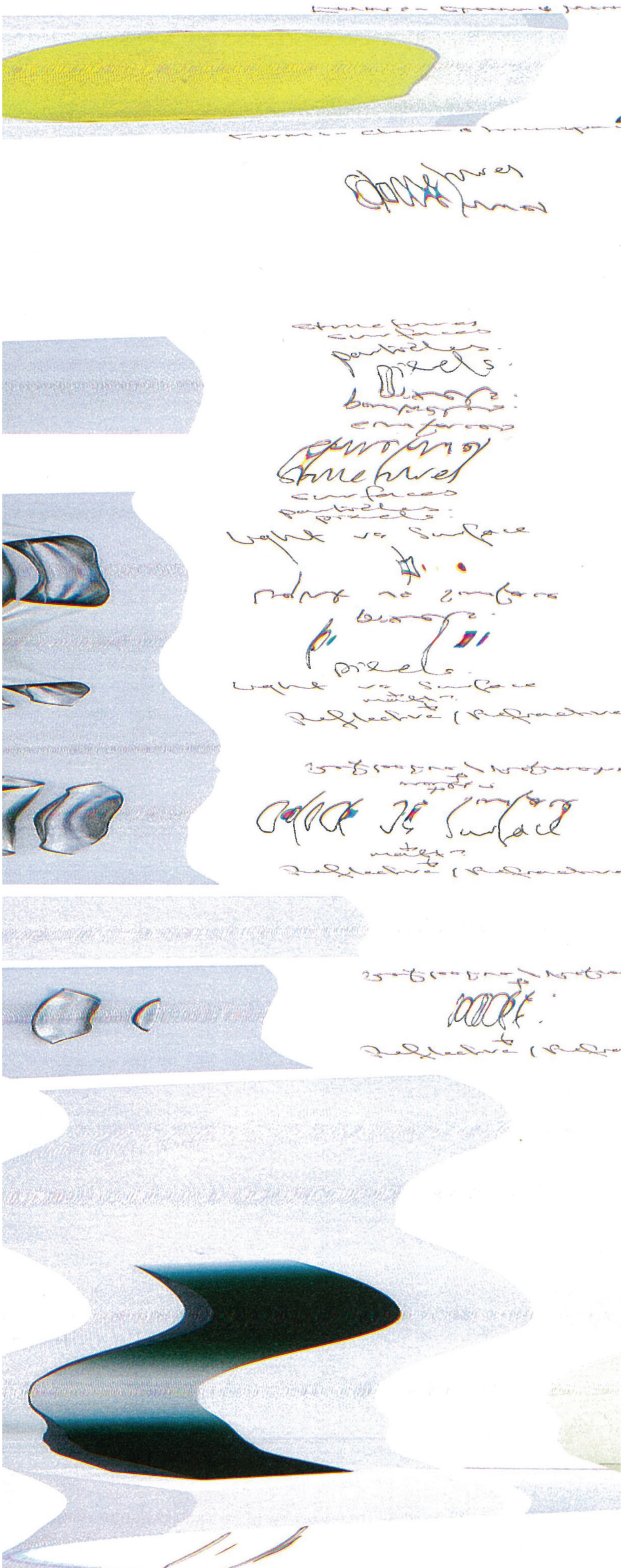


Fig 9. *Digital Scan of Concept Board.*

"Materiality itself is always already a desiring dynamism, a reiterative reconfiguring, energized and energizing, enlivened and enlivening. I have been particularly interested in how matter comes to matter. How matter makes itself felt." (Barad in Dolphijn & van der Tuin, 2012 p. 59)

"As connections of molecules made tangible in materials take on a presence in our lives without us even being fully aware that they do so, materials by design have become far more than the mere technical substrata of a world lived in analog to a digitized presence. Ready made with a use and a user in mind, virtually un-reconstructable yet affecting the very infrastructure of life, new materials challenge anthropology to respond with a theory of design that enables us to understand how materials work and what they do from a social science perspective."
(Küchler, 2011, p. 128)

Materials and materiality are fundamental components to this design-led body of work. To articulate a space in which materiality is explored the research draws inspiration from various ideas and concepts, assembling them across the horizontal axes of the established framework. Here the material and (im)materiality that constitute interactive textiles is explored through different but connected ideas, from micro to macro by way of forces, bodies, surfaces, structures, atoms and matter. Linguistically defining material and materiality is complex. At the most elementary level, a material can be understood as the physical aspect of things; the material is what builds the thing. However, material can also be understood as something that is composed of non-physical matter such as information, literature or music (Hong, 2003; Redströem & Mazé, 2005). Theories of materiality have been constructed around articulating the interrelationship between objects and subjects. Bruno Latour (1996; 2004) and Daniel Miller (2005) are just a few theorists who have located their work within articulating the increasingly invisible boundaries between objects and subjects and materiality and immateriality. Within their arguments, all 'things' can be understood as having a form of subjectivity, being, and agency of their own. Following this concept materiality departs from its most basic understanding of the quality of material or composed matter, to be understood as constituting technology, infrastructures, systems, and data. From particle, atom, molecule, fibre, yarn to textile, or from bits, code, data, files to a digital object, all matter in this practice is vibrant. '*Vibrant matter*' is borrowed from political theorist Jane Bennett (2010) who conceives all matter as vital, interconnected, and in-process with an agency of its own. Concepts put forward by New Materialist such as DeLanda (2004), Barad (2003, 2007) and Coole and Frost (2010) also reject notions of inert matter, rather articulating it as active and dynamic (Barad, 2003). For Barad matter is simultaneously acting on while being acted upon through a "stabilizing and destabilizing process of iterative intra-activity" (Barad, 2003, p. 822). DeLanda regards matter as having the capacity to act, transforming through interaction, with "matter-energy behaving dynamically" (DeLanda, 2004, p. 19) materiality is always in flux and emergent. In *Philosophy and Simulation: The Emergence of Synthetic Reason*, DeLanda (2011) extends his proposition that matter performs dynamically to include digital matter as well as physical matter.

Fig 10. *Digital Textile.*

3.1 Digital Textiles, Questioning Perceptions of Materiality

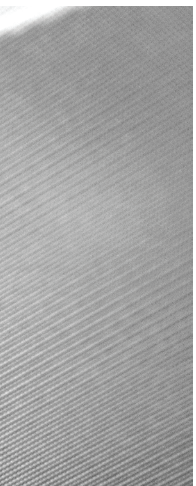
The ambiguous place of textiles as interactive materials makes explicit this new thinking about materiality and issues of subjectivity in relation to the object. The work of anthropologist Susanne Küchler becomes crucial in enunciating the perception of these new materials. She believes new materials, such as interactive textiles, express their agency explicitly, forcing us to revise our understandings of materiality. Küchler speculates that interactive textiles as smart materials "draw our attention to a material world that does not just represent who we are, but which is capable of standing-in for us, substituting for some of our own capacities" (2011, p. 132). In *Technological Materiality: Beyond the Dualist Paradigm* (2008) Küchler builds on notions proposed by Latour, emphasising the need to move beyond the "axis of duality implicit in much of social theory" in order see past the premise that there is a difference between the immaterial and the material. As technology becomes increasingly embedded in materials, conceptions of materiality and subject/object relations are made explicit - materiality itself "changing in front of us" (Küchler, 2008, p. 102). These concepts manifest in the surface and structure of the interactive textile, where the immaterial and the material function as one through non-conductive and conductive yarns, enabling the ability to react and interact in new ways, challenging our understanding of textiles.

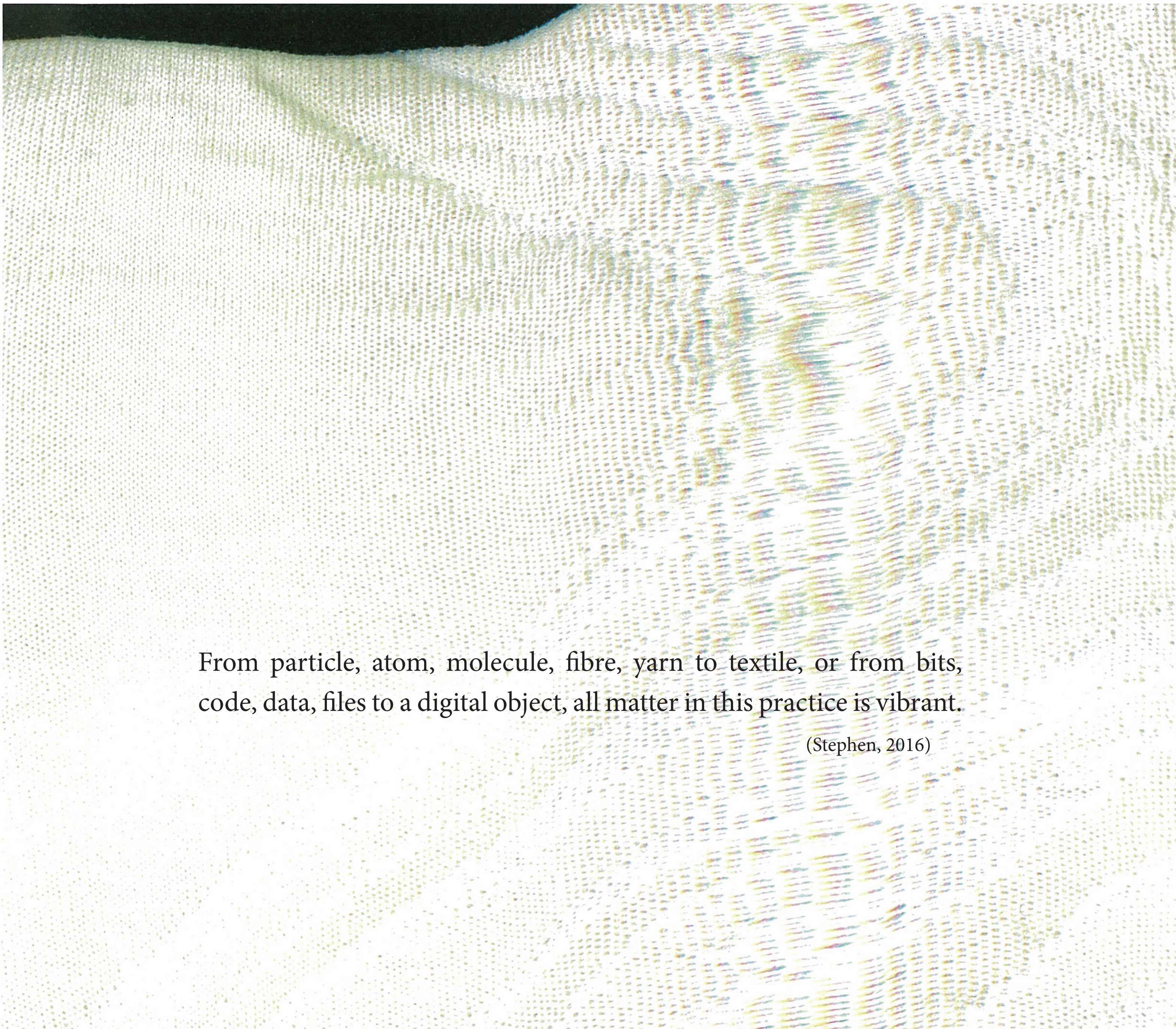
3.2 Digital Matter

In this work, materiality is understood to include both solid matter such as fibres and yarn as well as temporal intangible matter. Computational technology, also referred to as computational materials (Vallgårda & Redström, 2007), while being both abstract and concrete, is seen as a material for the design of knit structures. While this project does not solely focus on digital media, it is essential to examine theories concerned in placing digital materiality as computational materials are a vital part of the generative making processes established. Interactive textiles, or electronic textiles, are what Dunne describes as an "electronic object [...] on the threshold of materiality" (2005, p. 24). Dunne describes electronic objects as hard to define due to complex interrelations between the invisible and visible, energy and matter. van den Boomen, Lammes, Lehmann, Raessens and Schäfer extend this notion by identifying digital materiality not as im/material but 'in-material': "software, for instance, cannot exist by itself but is intrinsically embedded in physical data carriers" (van den.Boomen, Lammes, Lehmann, Raessens, & Schäfer, 2009, p. 9). *In New Materialism as Media Theory*, Parikka (2012) draws upon views of New Materialism and Jane Bennett's *Vital Materialism* to define a digital materiality. Digital objects are considered to be ingrained in "weird materiality inherent in the mode of abstraction" (p. 99) finding themselves interconnected, transient and 'vibrant'.

3.3 Matter Assembling/Collaborating Agents

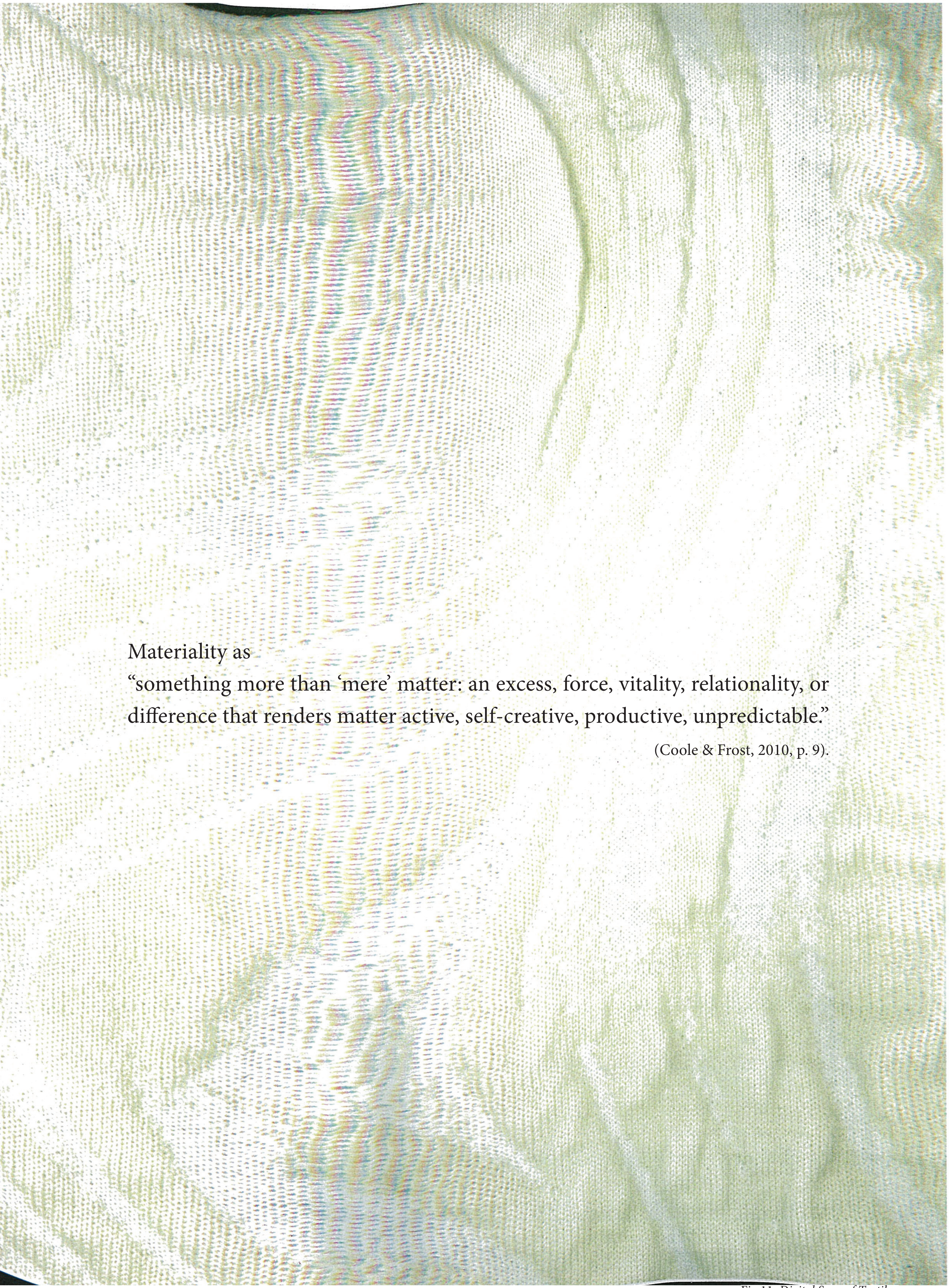
The notions explored above assemble to form a framework where materials become collaborating agents in the design process. Coole and Frost describe materiality as "something more than 'mere' matter: an excess, force, vitality, relationality, or difference that renders matter active, self-creative, productive, unpredictable." (2010, p. 9). This research draws on these new thoughts around materiality as self-creative and productive, actively assembling itself into new structures and forms (DeLanda, 2009). In this context dynamic matter and digital data became materials for a generative design process, where matter is decoded and recoded (DeLanda, 2011) as new knit structures are explored. Textiles simultaneously become both tools and materials to create with, the function of the developed textile, digital or physical, is to generate new knowledge in the designing of interactive textiles.





From particle, atom, molecule, fibre, yarn to textile, or from bits, code, data, files to a digital object, all matter in this practice is vibrant.

(Stephen, 2016)



Materiality as
"something more than 'mere' matter: an excess, force, vitality, relationality, or difference that renders matter active, self-creative, productive, unpredictable."

(Coole & Frost, 2010, p. 9).

Fig 11. *Digital Scan of Textile*

Chapter 4. Informing Methodologies

This section unpacks the methodological frameworks supporting the practice-led research - an investigation of interactive textiles as generative design materials. The methodology was not linear and explored the potential of a practice-led, open-ended approach. A dialectical structure (Benjamin, 2002) was identified to help locate the focus and scope of the project, and the inquiry began at the centre of this framework; the centre being the site of intersection between material and making. The research investigations were rhizomatic with “no beginning or end; it is always in the middle, between things, interbeing” (Deleuze & Guattari, 1987, p. 25). This mode of working allowed for lines of investigation to grow, branch and network, (Ingold, 2008) eventually being manifest in an assemblage of practice-led design outputs (Deleuze & Guattari, 1987; DeLanda, 2006; Bennett, 2010).

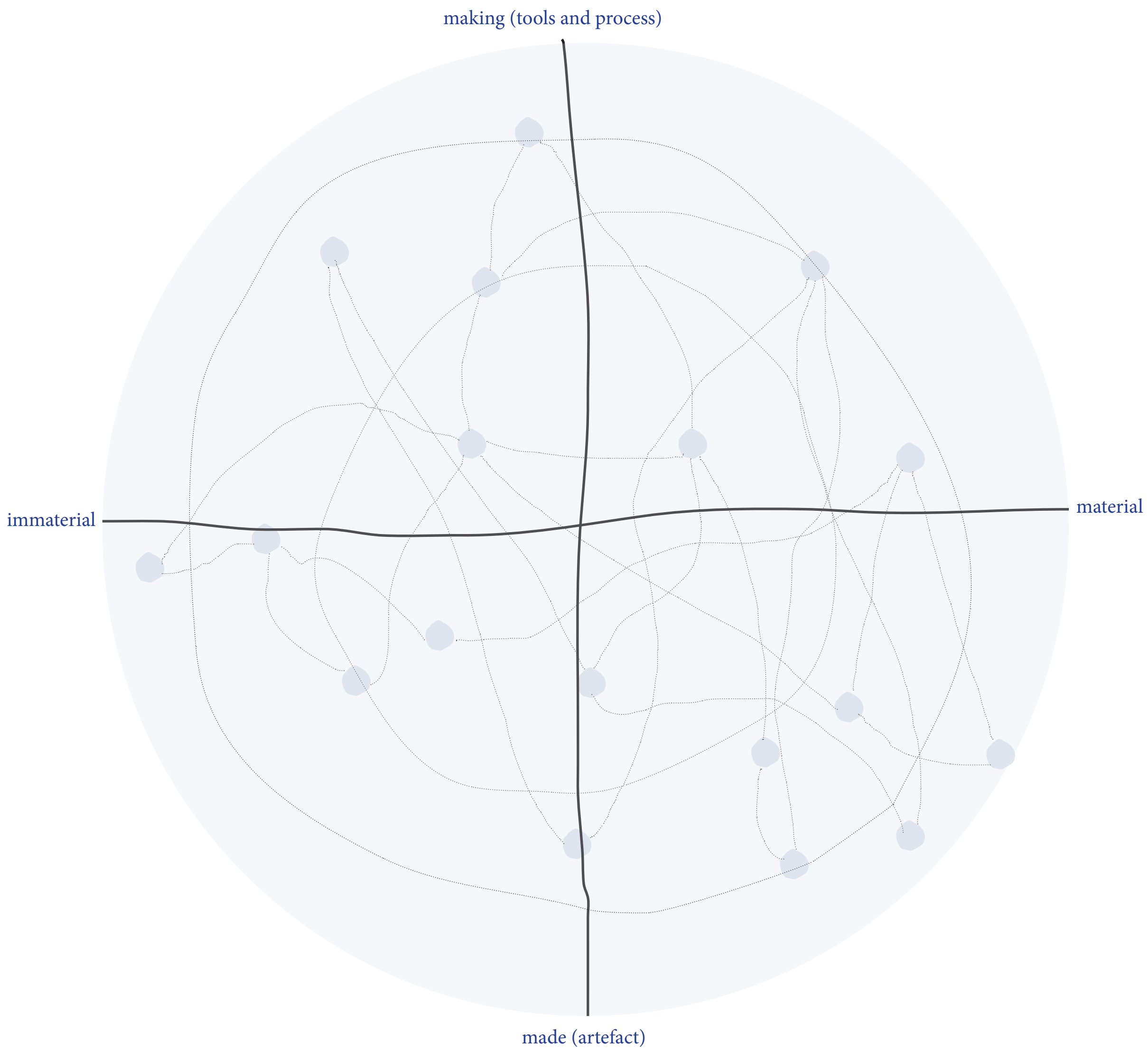


Fig 12. *Expanded Dialectical Framing for Research.*

4.1 Practice-led Research

Practice-led research allows for making to generate an enquiry. The investigation, in turn, generates new ways of making. In this sense practice-led researchers 'perform' practice to produce new knowledge, emerging from the act of making. Haseman echoes this sentiment stating researchers "dive in [and] commence practicing to see what emerges. This is not to say these researchers work without larger agendas or emancipatory aspirations, but they eschew the constraints of narrow problem setting" (2006, p. 4). Scrivner (2000) notes the act of making and the generating of original artefacts is the primary focus and becomes the main outcome of practice-led research. However, the contribution to knowledge made through practice-led research can (and in this research does) extend beyond the artefacts produced. The practice-led approach in this investigation allowed for new methods of designing interactive textile artefacts to emerge out of the act of making.

4.2 Experimental Research Through Design and For Design

Experimental approaches in this practice were imperative in activating the potential formulation of new knowledge and new methodologies. In *Becoming Materials: Material Forms and Forms of Practice*, Bergström, et al.(2010) indicate that their practice-led approach facilitates the development of new working methods and techniques, allowing for unexpected aesthetic effects to emerge. They note that experimental research through design involves creating material samples to "explore aspects of the potential or eventual expressiveness of the material, to open up a design space for understanding the consequences of a particular material for design and for use" (Bergström et al., 2010, p. 164). Frayling (1993) divided art and design research into three approaches; research in art and design, research through art and design, and research for art and design. While this research connects with all sections at different times, most of the research is conducted as research through design. Researching through design is practice led and the process of creative production in this thesis is understood as an important research method. Working in this mode of research through design in the investigation of expressive materials allowed the act of making to develop and grow, engendering lines of experimental methods and new knowledge. Thus the project is also a form of research for design in that it contributes new knowledge as new design methods.

4.3 Interactive Design Methodologies

As this research is concerned with the unfolding of interactive textiles in a dynamic design process, methodologies of interaction design were considered. The term interaction as used in this research is nuanced: interaction between materials and designer becomes a generative tool in the design process, and the designed outcomes are interactive artefacts. Interaction design and associated research is the study of human-computer interaction and the functions of computational objects (Mazé, 2007; Wiberg, 2012). As interactive textiles have computational elements embedded, interaction design research has contributed to the designing of the textile structures. *Methodology for Materiality: Interaction Design Research Through a Material Lens* (Wiberg, 2013) suggests a new methodology for interaction design. This research extracts elements from this methodological proposal by using a dialectic framework for working "back and forth between materials and materiality, details and textures" (Wiberg, 2013, p. 626). The 'back and forth' nature of this approach allowed for a type of 'dialogue' to emerge between the materials and the designer, developing and extending knowledge through and about the making of interactive textiles.

4.4 Generative Systems

Generative design is a mode of designing which involves making via sets of rules or parametric process and is typically composed using algorithm editing software. McCormack, Dorin and Innocent state "generative systems offer a methodology and philosophy that view the world in terms of dynamic processes and their outcomes" (2004, para. 3). Generative design systems are interactive; artefacts are emergent and are a result of feedback loops between maker and materials. Systems of design, such as parametric modelling, enable the exploration of material configurations that would be otherwise inaccessible through traditional textile design methodologies. This research does not employ generative design as an art form or design style, nor as a purely machine based system. Rather it engages and adapts a generative design process where the designer utilises both digital systems - through the use of digital knit technologies and through testing the behaviour of smart knitted textile structures - and tacit designerly knowledge for the creation of new textile designs. This research explores interactive textiles and their emergent potential as physical and digital material structures continually giving form to new structures by way of selective, programmed interactions.

4.5 Craft Practice Informing Digital Knitting

This design practice primarily engaged digital knitting as both a mode of designing and a process of making. Digital knitting involves programming and fabricating knitted textiles. The knitting explorations for this research were developed on Shima Seiki's industrial machines. The programming of knit structures were crafted within Shima Seiki programming interface SDS-ONE system. In the doctoral thesis *The Design of 3D Shape Knitted Preforms* Underwood argues digital knitting can inform "current design debates [around] new technology and materials for design, the reconsideration of craft in a digital context, and the interplay between design and science" (2009, p.1). Trajectories between craft practices and digital technology are continually expanding and opening up opportunities across art, craft and design platforms. In *Abstracting Craft: The Practiced Digital Hand* (1996) McCullough articulates how the emergence of computation has given designers and artist new types of digital mediums to create with. However, trajectories between craft practices and digital knitting have not been as strongly established. Access to knitting technology in most academic settings and in industry remains in the domain of knitting technicians (Taylor & Townsend, 2014; Underwood, 2009) thus the designer has little opportunity to engage with digital making. In *Reprogramming the Hand: Bridging the Craft Skills Gap in 3D/Digital Fashion Knitwear Design* Taylor and Townsend state this division is possibly due to "the complexity of the software and limited access to industrial machinery" (2014, p.1). They continue by emphasizing how designers engaging with knit technology, in collaboration with knit technicians, can establish new methods of designing that can "contribute towards the development of new manufacturing models based on the possibilities of future fabrication" (2014, p. 24). The literature analysed here raises questions around what embracing digital knitting as a mode of making can mean, and what digital advancements in knitting technology can offer a new textile knit design paradigm. This research draws on tacit craft knowledge while placing the Shima Seiki knitting machine, the SDS-ONE program interface and corresponding digital tools as extensions of the hand in making. Exploring the intricacies of the design system allows for creative development and generates new ways of interacting with digital knitting.

Fig 13. *Knitted Textile 14*

Chapter 5: An Intertwined Process

5.1 Introduction

Aspects of different methodologies have been assembled and merge to create an overarching framework to establish a new textile design methodology. Massumi states "Whenever we diverge from rules and habit in thought or action, we create new connections, actualize virtuality as it appears 'in the twists and folds of formed content, in the movement from one sample to the other" (2002, p. 133). The methodological approaches utilised have enabled an exploration and development of new methods that provoke divergence and disruption to break away from conventional textile processes. The next section of this thesis describes and discusses the research process further, intertwining research and making, and leading to a new design process.

5.2 Expressive Components: Conductive Stitch Structures

As a foundation for the project, a series of digitally knitted textiles were developed to investigate the effects different conductive yarns and stitch structures have on the sensing properties of interactive textiles. This exploration was a collaborative process between a fellow researcher Hollee Fisher. Shima Seiki's programming interface became an electronic canvas, drawing and placing the digital components translated as instructions for the knitting machine as a means of creating structure and form. The knitting machines operate via code which is 'written' in the SDS-ONE Knit-paint system; the coding language is represented as a two-dimensional cluster of colour values. These colour values determine how individual needles on the knitting machine will perform. The textiles are formed in an intarsia structure; each section is isolated and knitted with its yarn carrier (fig. 17 & Appendix A). With the inclusion of conductive yarn, the isolated stitch structures within the textiles emerge as sensing mechanisms; digital materiality here is intertwined within the physical knitted structure.

When coupled with a microcontroller (such as an Arduino) and computer interface, reactions and responses visually manifest through conflicting yarn composition and different stitch assemblies (refer to Appendix A). DeLanda's assemblages are composed of matter and expressive components. Here the stitch structures and conductive yarn become vibrant components, moving through stabilised and destabilised states (DeLanda 2006). Within the knitted textiles the conductive stitches become sites of reaction, interacting with each other differently depending on stitch structures.

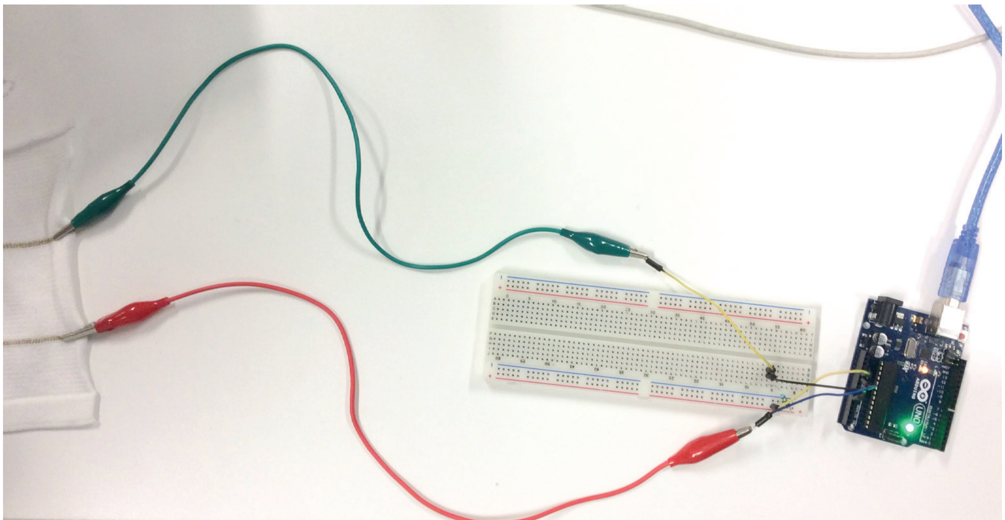


Fig 14. *Textile/Arduino Capturing Interaction*

5.3 Embodied Making: Collecting Data

Being dynamic, the knitted textiles and corresponding electronic attachments have the means to communicate, to express and to record information. As the textiles were manipulated through performed actions the level of resistance running through the stitch structures continually shifted, responding to the force of the interactions. The responsive nature of the different stitch components was 'captured' as fluid numerical readings, and stored within digital files. Physical interaction with the textile is translated into transmutable digital data, materially defined by their fluid and fluctuating disposition.

The creative process here manifests as embodied interactive emergence (Sampson, as cited in Bolt, 2007), the designer and the materials performing as collaborating agents. For Sampson, creative outputs are a result of co-emergent properties between actors within an 'acting ensemble' (Bolt, 2007). In this project, data is captured through body/textile interaction, and agency is explicitly no longer just at the site of the designer. The acting ensemble involves maker, yarn, textile, electronic components, electronic currents and force. All of the elements of the interactive textile act and react in unity; the yarns and fibres, the textile itself, the computer and resulting digital data sets all have integral agency and co-agency. Bolt suggests that by shifting our focus in this way "the acting ensemble rather than the artist as the locus of art enables us to come closer to an understanding of the dynamism of material practice and to the radicality offered by the notion of material thinking" (Bolt, 2007, p. 4). Here along with the yarn, textiles and electronic forces, the data captured as a result of the embodied interaction became a medium to create new forms with, a material with its own dynamic agency that generates the next phase of the design process.

5.4 Generative Structures

Expanding on concepts discussed by Bolt and Sampson (Bolt, 2007) this project positions objects (physical and digital materials) and subjects (humans) as not independent of each other, but as one in the same in the making process. Notions of dualisms are disputed to allow for new ways of thinking and making textile structures through material agency. Barad introduces the term "intra–action" as the site where "subject and object emerge" (Dolphijn & van der Tuin, 2012, p. 55). To extend and perhaps diffract on notions of intra-action this research proposes matter, such as data sets, emerge from the intra-action within 'entangled agencies' (Barad, 2007, p.33). Once the embodied data had been collected the design process shifted to a parametric mode of making.

Here the data is 'crafted' into digital simulations to inform new knit structures. 3D modelling software Rhino (http://www.rhino3d.com/) and the visual programming interface Grasshopper (http://www.grasshopper3d.com/) were used to facilitate this phase. In Grasshopper an algorithm was formulated to process the data collected; this algorithm generates the structural trajectories allowing for the emergence of the digital artefact. Utilising Grasshopper as a visual form of coding allowed for the data sets to take shape as generative algorithms within the 'acting ensemble' of designing. Generative design can offer new modes of making based on "the incorporation of system dynamics into the production of artifact" (McCormack, Dorin, & Innocent, 2004, para. 3). There was no predetermined outcome defined, the process of generative design was open-ended to allow for algorithms to inform the digital structures. In Grasshopper, the data with its numerical value is plotted out along a line, each line representing a single knit structure with its individual stitch structure, i.e., interlock, tuck.

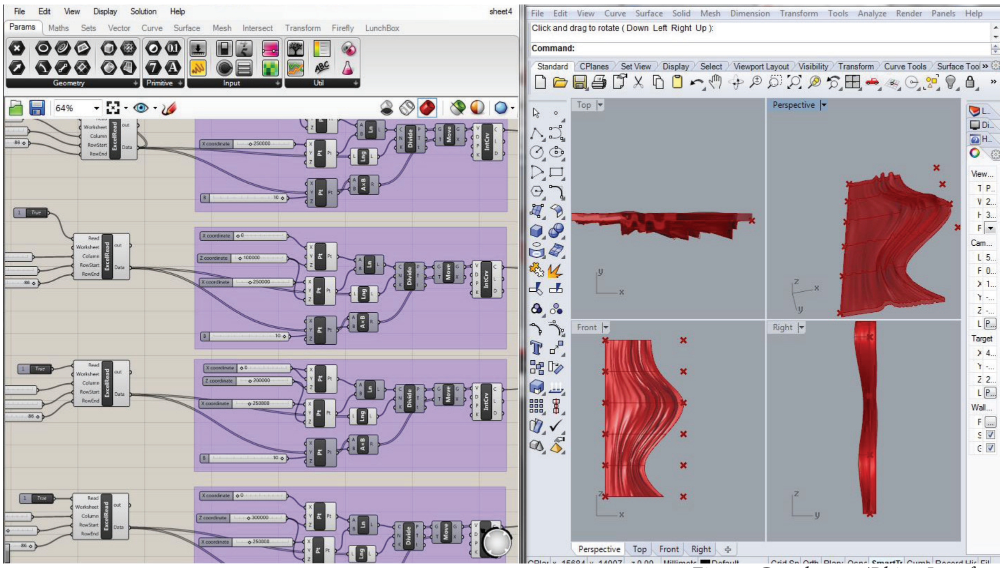


Fig 15. *Grasshopper/Rhino Interface*

The trajectory points map out the embodied interactions with the knit structures, and when the Interpolate Curve component traces the data points the digital simulation forms a structure. A surface is then created and charted across the points on the curved lines. The loft of the surface can be manipulated via a number slider. The digital artefacts are determined by transmutable data values creating a textile topography, mapping out data collected from past events. Here the making of the computational textile draws on notions of 'matter-energy flow' established by Deleuze and Guattari (1987). The algorithm created in Grasshopper is 'rhizomatic' as it enables experimental flows of computational energy and digital matter, where concepts and actions merge. In *The Textility of Making* Ingold (2009) expands on Deleuze and Guattari stating "forms of things arise within fields of force and flows of material" (p. 91). These notions of 'matter-energy flow' fold together conceptually and methodologically in the design process. Ingold (2013) defines the process of making as a process of growth to "place the maker from the outset as a participant in amongst a world of active materials" (2013, p. 21). He sees material and consciousness of the maker flow together in dialogue informed by action and perception, a type of thinking through making. This process of thinking through making informs the generative design process as new textile structures emerge. Parametric modelling allowed for a process where "conceptualisation shifts from the primacy of objects to envisaging interacting components, systems and processes" (McCormack, Dorin, & Innocent, 2004, para. 3) to generate new forms and artefacts. In a traditional design process, the designers primary objective is to develop an object with outcomes defined before commencement. In a generative design process, however, the designer does not create the artefact itself; alternatively, the designer creates the situations from which the artefact emerges.

The digital models generated are 3D printed to examine further the structure and inform the next phase in the process. This iterative process, as the artefact emerges, informs either the refinement of said artefact or the making of new artefacts. Stiny (2006) explains a digital model is created via a set of rules developed by the designer (rules are built in Grasshopper for this research), the designer then modifies the set of rules to refine the design. He refers to this iterative process as 'recursive' and 'embedded' (Stiny, 2006). This recursive nature of the design process allowed for what Schön refers to as a reflective practice. Here an active dialogue (Schön 1983) between designer and materials informs the next phase of the design. While there were flaws in the first iteration, practical modifications were implemented for the successive iterations. On reflection, it was also noted the physical artefact (fig 16) spoke of an unravelling through material states, the beauty in form conceptually underpins the next phases. Software technology in this body of work was exploited to intersect and generate new textile structures; crafted layers of data became rendered into 3D materials, enabling the production of forms and surfaces adaptable for further textile generation.

Fig 16. *Iterative process/Artefacts emerge*

Fig 17. *Conductive Kint Structures/Data Sculptures*

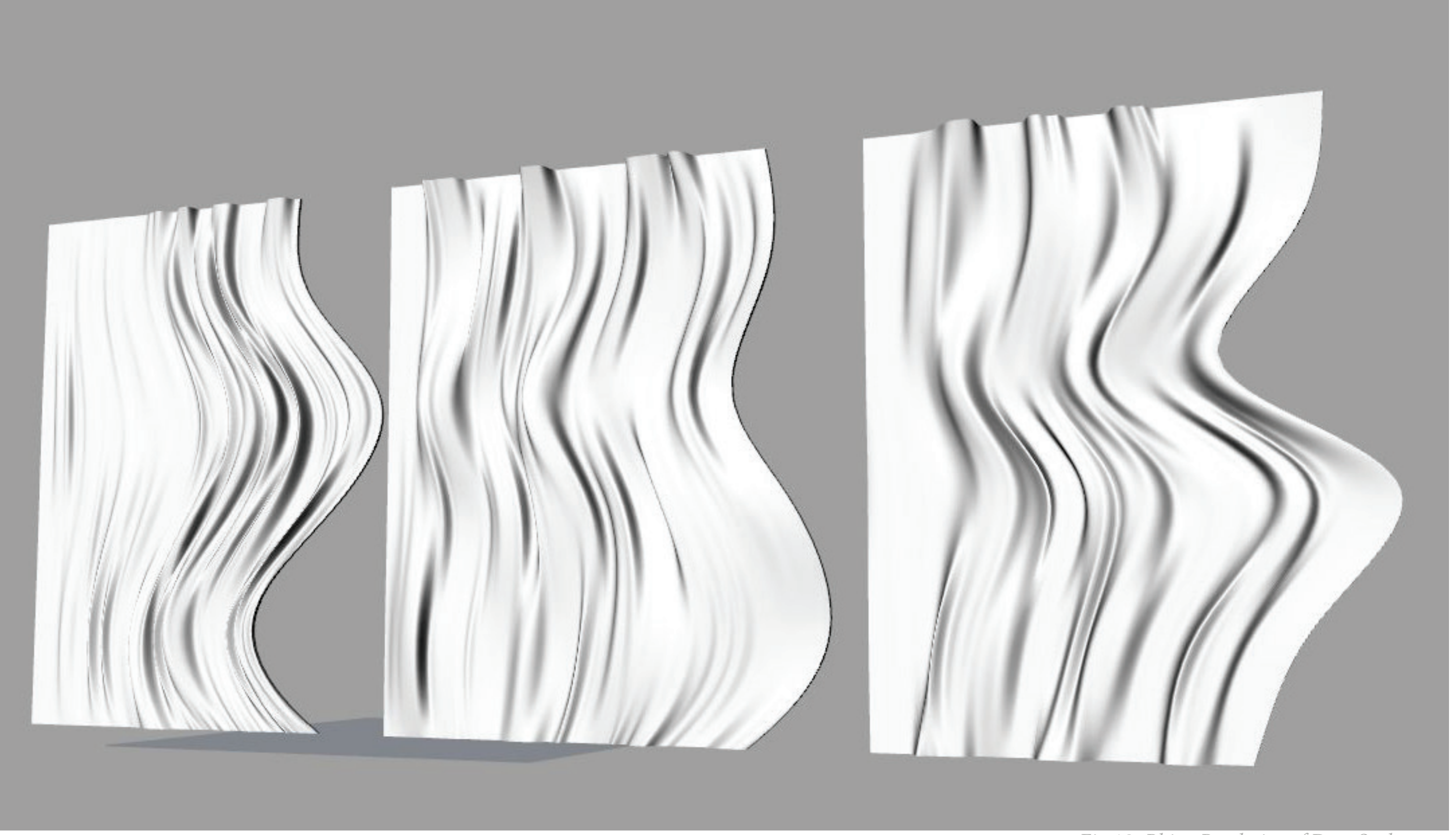


Fig 18. *Rhino Rendering of Data Sculptures.*

Software technology in this body of work was exploited to intersect and generate new textile structures; crafted layers of data became rendered into 3D materials, enabling the production of forms and surfaces adaptable for further textile generation. (Stephen, 2016)

Fig 19. *Data Sculptures*

5.5 Digital Knitting: Rhizomatic Approaches

As with the previous explorations, programming again is utilised to exploit and intersect the process of textile making. Here the writing unpacks a shift in parametric modelling back to Shima Seiki programming to further explore matter as an active material agent in the design practice. Teal describes design as revealing a "richness of the world. However, this richness gets diluted when design is imagined to be merely a series of iterations along a linear path" (Teal, 2010, p. 295). This practice diverges from linear processes commonly employed in textile design, operating in an open-ended manner to allow for materiality *in-process* (De Landa 2004; Barad 2001, 2003; Coole & Frost 2010) to inform making. The process is rhizomatic, as material interactions generate explorations for formulating new textile design methods.

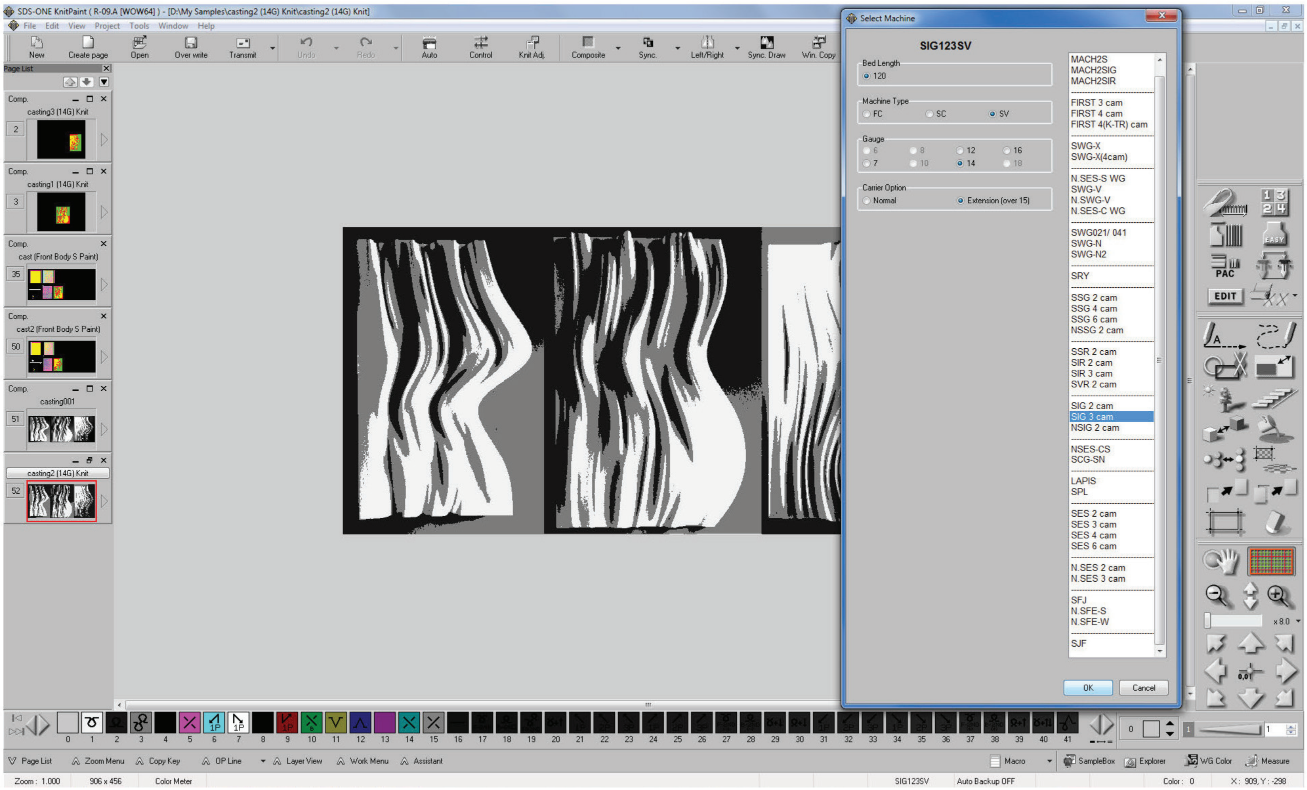
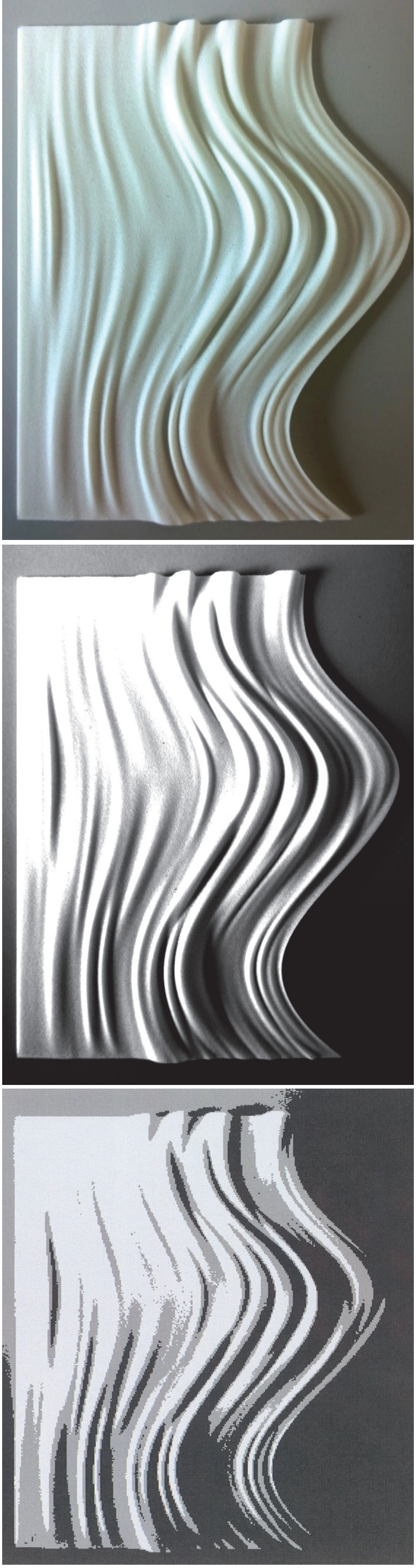


Fig 20. *Shima Seiki knitting CAD/CAM system Converting to Knit Structures*

5.6 Digital Matter Moving through Material States: Reactivating Knit Structures

To shift the work back into a digital platform the physical three-dimensional data structures were scanned and transformed into JPEG files. The designer then imported the JPEG files into Shima Seiki SDS-ONE design system where the images were converted into stitches structures. Here the project considers and further interrogates materiality through generative states, drawing on Parikka's (2012) ideas of vibrant digital materials, emergent and abstracted in material state. Material artefacts once again become immaterial, fluid and adaptable as they shift between digital environments (fig. 21). The process of making is situated in Shima Seiki knitting CAD/CAM system and its SDS-ONE Knit-design program. Here the programming interface allows for image files to be imported and transformed into jacquard stitch structures, according to gauge. Unlike the opportunities presented in Grasshopper/Rhino modelling, in Knit-design the rules are predefined by Shima Seiki although parameters can be altered, allowing for different structures to emerge depending on value inputs (fig 20). This process is likened to the common textile design method of sketching out ideas. However, the practice of sketching unfolds differently to conventional design methods as there is no 'blank' work screen or paper and the process involves the contingency of digital matter.



"A JPEG of a sculpture and the physical sculpture are not the same thing, but they are related. They are able to live separate but entangled lives, and so the overall object that they constitute is neither physical nor digital, but an amalgamation of both" (Openshaw, 2015, p. 7)

Fig 21. *Scan/JPEG/Knit Simulation Mapping*

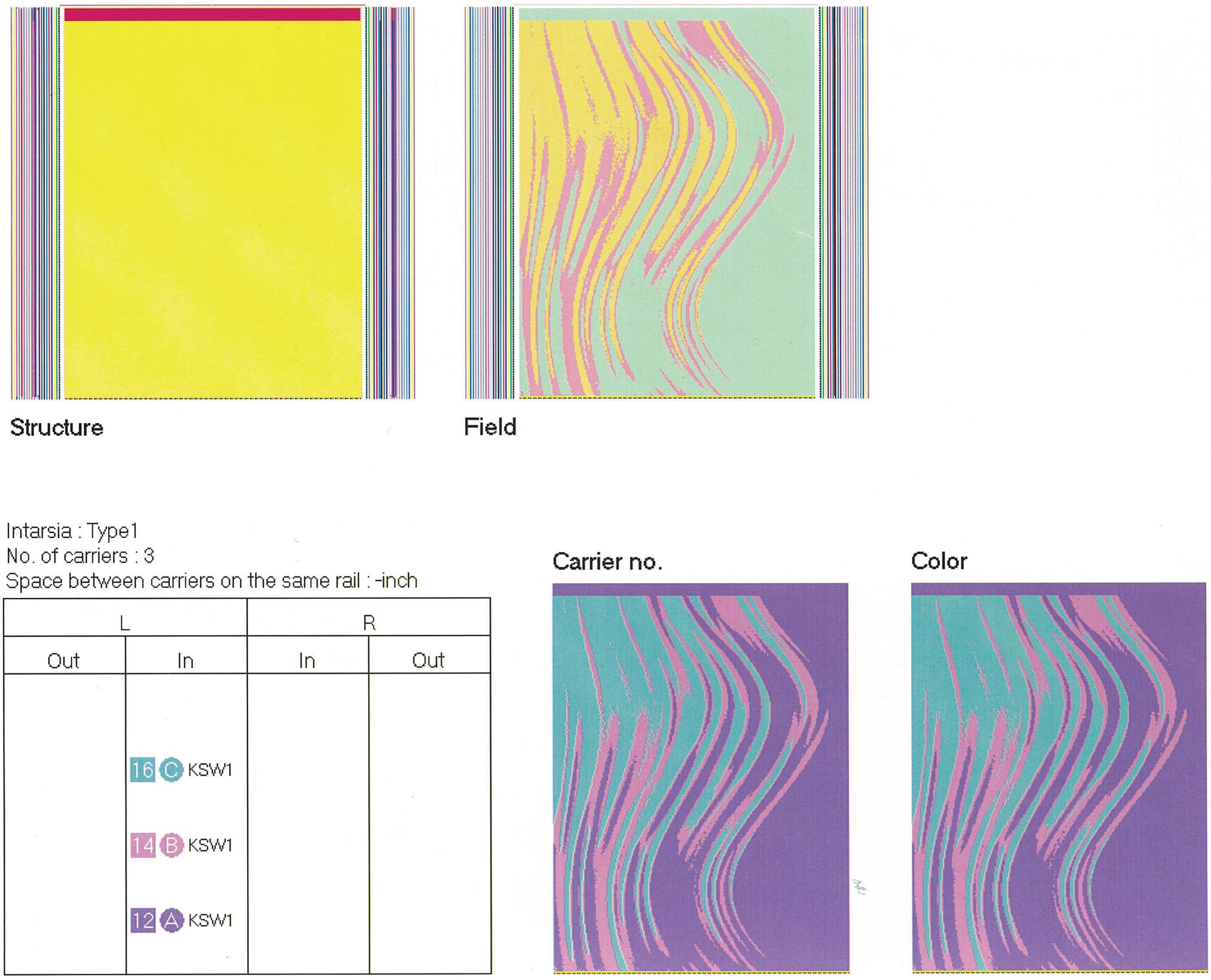


Fig 22. *Shima Seiki Notation for Knit*

In a similar manner to operating in Grasshopper and Rhino interfaces, the computational sketching engages in elements of uncertainty, contingency and indeterminacy that "should be taken as virtualities - modes of reality implicated in the emergence of new potentials, producing actual experience" (Marenko, 2015, pg 111). The possibilities for the emergence of the unexpectedness is embraced in the design practice.

The process moved back into Knit-paint, where the technical programming for the structure occurs before it is processed to be digitally knitted. As previously explained, Knit-paint is a graphical interface which involves Shima Seiki's programming language and technical operations. The programming and machine control data are based on colour and number representations. Once the stitch programming is complete, the option lines and pattern development assignments are set (Underwood, 2009). The option lines are the coloured vertical lines that run the length of either side of the knit structure and hold the information for the machine during the knitting process. As the knit structures of the digital models are processed through the Knit-paint program design interventions present themselves in the form of *development data*. The processing pages display data images of formulations that instruct the machine how to knit the specific piece (fig 23).

Shima Seiki programming involves a series of stages to transform the knit design into a code using the CAD/CAM system. This data is saved and becomes the file that is transferred to the knitting machine. Programming a design is commonly a knit technicians role (Underwood, 2009; Smith, 2013), however in disrupting traditional textile practices, this process embraced the technical programming interface as it allowed for insight, development and, importantly, computational material to surface.

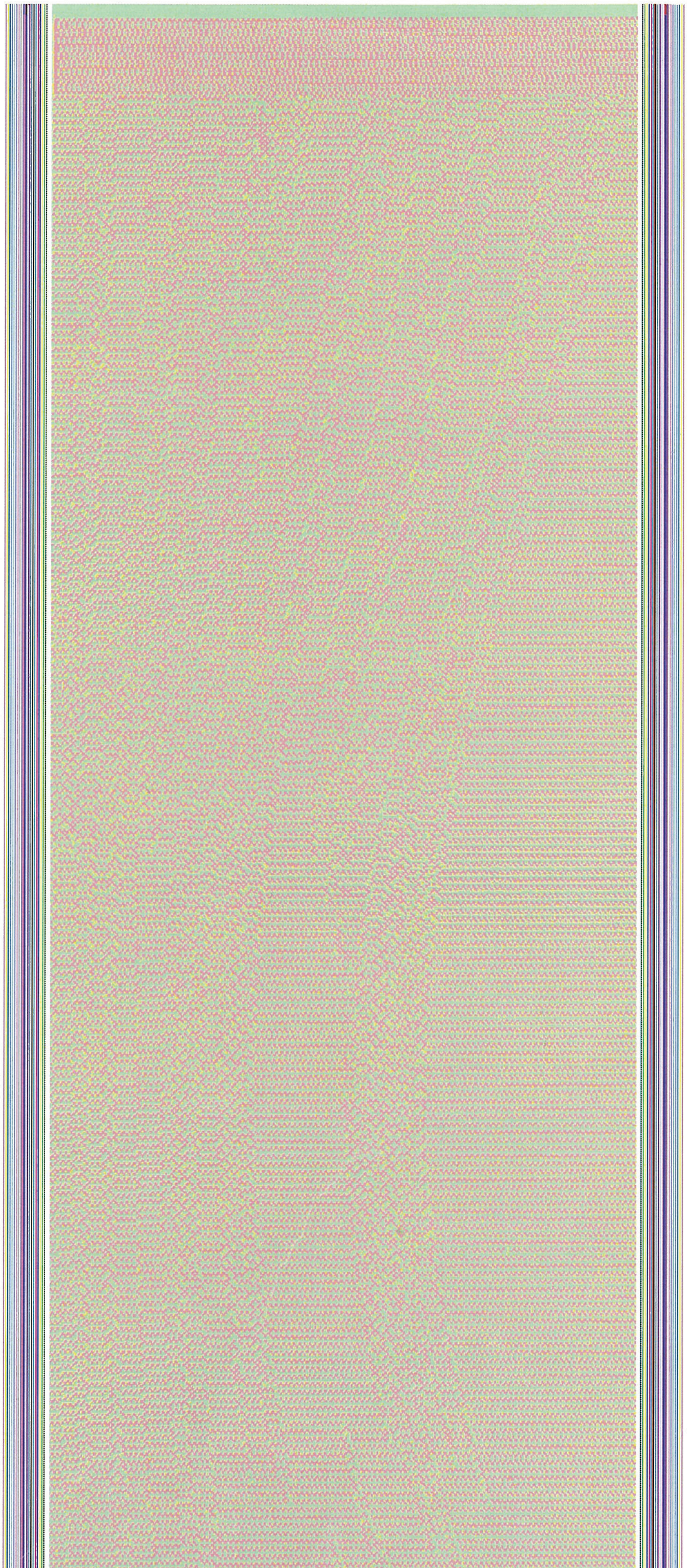


Fig 23. *Collecting Shima Seiki Development Data*

5.7 Collecting Digital Knitting Data as Material to Design With

Here the practice and the digital and physical artefacts emerge as interconnected, transient and 'vibrant'. Methodologically the practice is rhizomatic as multiple disparate but intertwined design paths present themselves, assembling potential outcomes. In *The Agency of Assemblages* Bennett (2010) proposes concepts of efficacy, trajectory, and causality to define the actions of entities acting within assemblages. Efficacy is "the creativity of agency, to a capacity to make something new appear or occur" (p. 31). Trajectory becomes "a directionality or movement away from somewhere even if the toward which it moves is obscure or even absent" (p. 32). Causality becomes the emergent "what makes the event happen is precisely the contingent coming together of a set of elements" (p. 34). These notions of efficacy, trajectory, causality become an important way of thinking through this design process, where materials and digital data are considered dynamic and active in the design process and contribute to the generating of new textile structures. As the jacquard structures were knitted, their corresponding data pages were 'captured', turned into JPEG formats then processed back into Knit-design and Knit-paint interfaces (fig 23) where they to are transformed into new jacquard knit structures. Efficacy here is seen as the co-agency of the designer and the program as the knit structures are processes, trajectory becomes the data simulations that materialise in the process, and causality is what emerges as the structures are digitally knitted.

5.8 Crafting Digital Data

This generative act of designing with data is a process of decoding and encoding matter as digital materiality through modes of abstraction (Parikka, 2012). Crafting within digital and virtual interfaces have created new types of medium (McCullough, 1998) and technology is treated not only as a tool but also a material for design where computational bits are actualised into physical atoms. This process of rendering the knit data back into new knit structures draws on notions of hacking (von Busch, 2007) the software against its automated linear operation. Establishing a process of generating knit structures by diffracting and capturing data allowed for resultant structures and patterns to appear which would have been difficult to achieve otherwise (Fig 24, 25, 26 & 27).

Fig 24. *Data Sculpture Knit 16, and Data File Knit 17*

Fig 25. *Data Sculpture Knits 1-6, and Data File Knit 7*

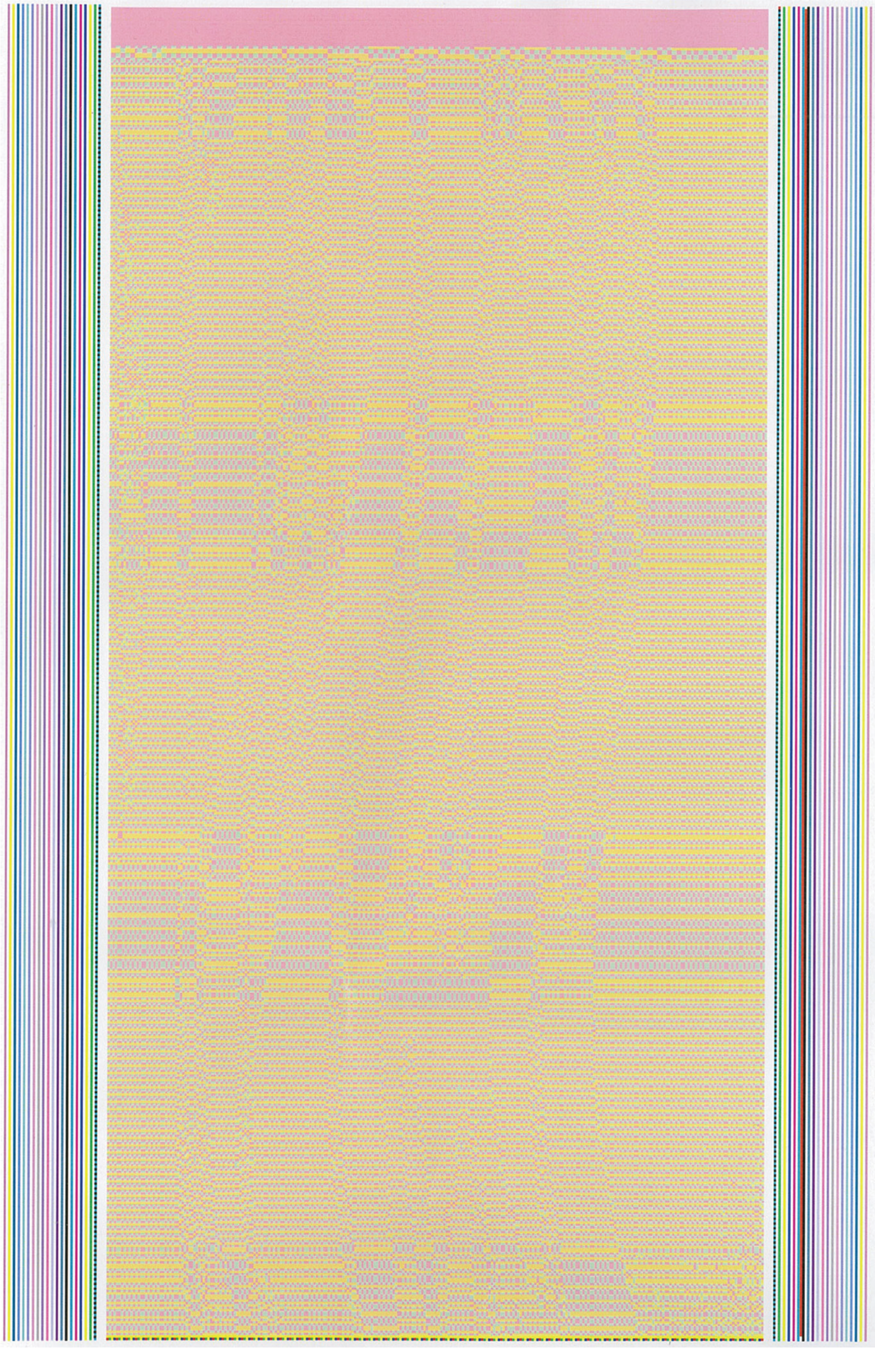


Fig 26. *Condensing Shima Knit Data*

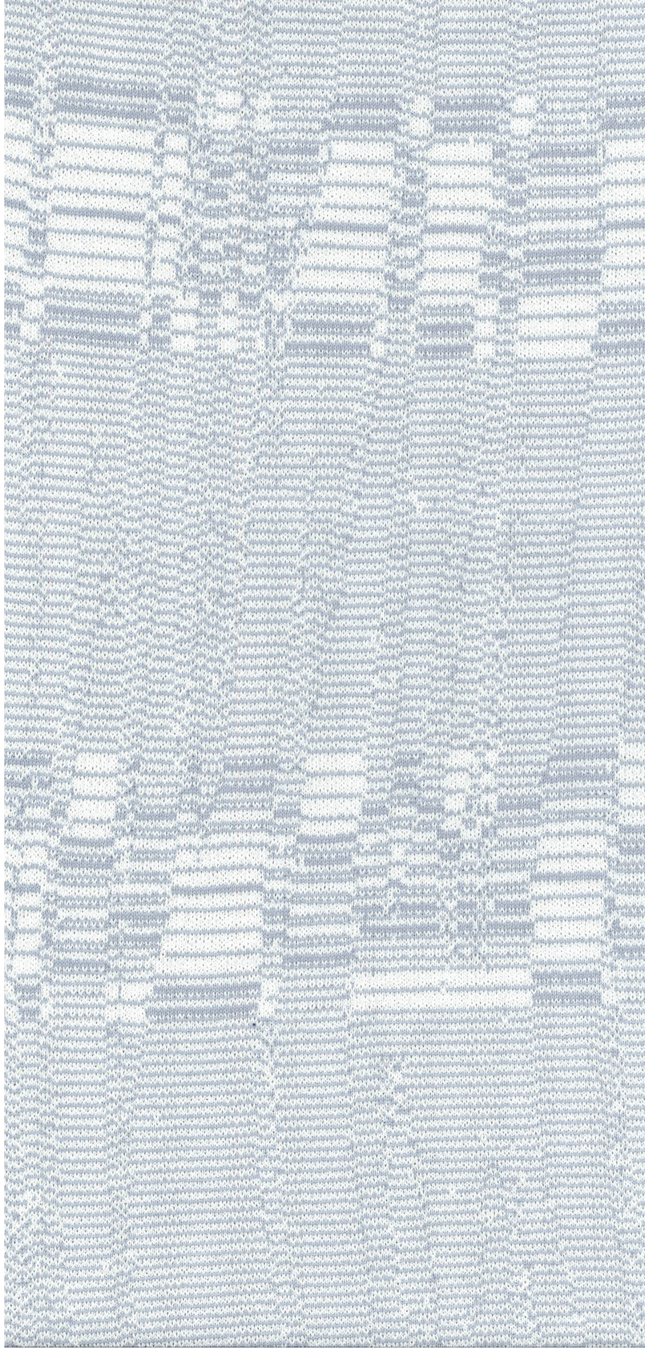


Fig 27. *Data File Knit 20*

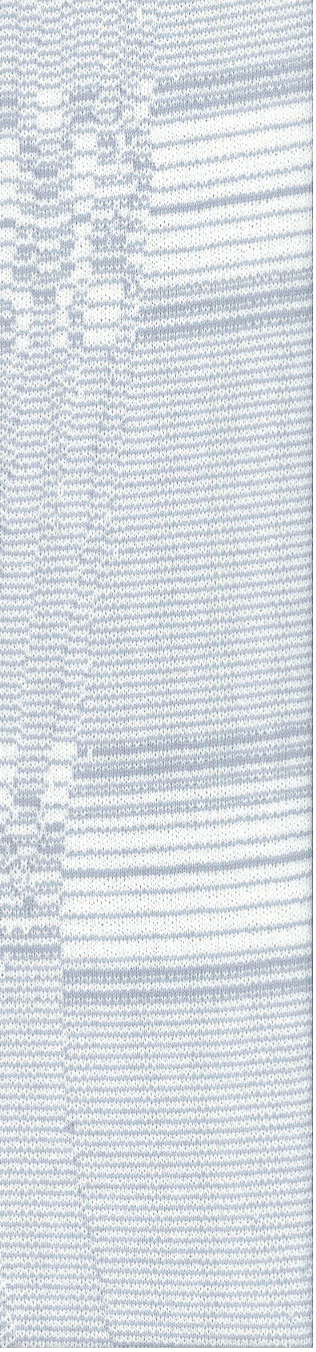


Fig 28. *Data Sculpture Knits 14 and Data File Knit 20*

5.9 Matter/Material Qualities

As the digital knit programming unfolded, so to did the development of tangible knitted textile structures. This section unpacks the important role yarn played in this rhizomatic design process. Every yarn comes with its own set of properties and capabilities; these allowances render them collaborating agents in the exploration of new generative modes of making knitted textiles.

A 'material library' was created as part of the investigation, categorising yarn information, construction notes, material properties and potential applications. Miodownik (2015) notes material libraries are "repositories of knowledge", where access to material samples "is the crucial aspect of these libraries, because many aspects of materials are currently unquantifiable, and so a hands-on sensory interface is seen as a vital part of the design process" (pgs. 69-70). Yarns were sourced from across three major areas of yarn and fibre development - scientifically developed yarns, engineered innovative natural yarns, and hybrid yarns containing natural and conductive fibres. The scientifically developed yarns included a range of conductive yarns, plasma silver coated yarn, solar reactive fibre, Kevlar – an extremely strong yarn, and Pemotex - a flame-retardant filament. The engineered naturals comprised of Merino and Alpaca wools, Seacell - lyocell yarn from seaweed, organic cotton, nettle fibre and milk fibre. The hybrid yarns included bamboo and copper, silk and stainless steel, and linen and stainless steel (see Appendix B). This process of collating yarns into basic knitted samples was more systematic in its approach than other phases of this research, but the outcome allowed for insight into the potential behaviours and knitting capabilities of a range of yarns.

As the yarns were combined and digitally knitted into the more complex generative structures, the material agency or effectivity of yarns and programmed stitch compositions create 'sites' of reaction as unexpected three-dimensional surfaces developed. This phase of the process was experimental, testing the knitting files and merging yarns into surface and structure is an act of "bringing together diverse materials and combining or redirecting their flow in the anticipation of what might emerge" (Ingold, 2008, p. 94). The inclusion of conductive yarns such as silver and stainless steel blends render the knitted structures as interactive textiles, capable of responding to electronic currents.

Designing interactive textiles requires an understanding of their inherent fluid and temporal properties. This research adopted a methodology proposed by Wiberg (2014) where designing engaged in a back and forth of thinking and making between details and wholeness, materials and textures. This approach activated a mode of working between 'materials' and their properties and 'wholeness'; the way in which the material compositions assemble for 'use'. 'Use' in this research was defined by the artefacts ability to open up more generative modes of making. Wiberg further articulates the value of reflective practice and craft approaches in gaining a better understanding of materiality in interaction design. Documentation and notes of these digital files and the emerging knit structures were collated in journals (fig. 22, 29). These journals allowed for reflection and led to a deeper knowledge of the inherent properties of physical materials including how they react against one another within the knit structures and how they respond to environmental (such as steam, fig. 30) and electrical stimuli. As the textiles are considered active in the creative process (Bolt, 2007), keeping journals and notes were imperative for what Schön describes as a "reflective conversation with the materials of the situation" (1983, p. 175) to emerge. The designer's workspace also became a space for reflection as concept boards and material samples were created (Fig. 31 & 32).

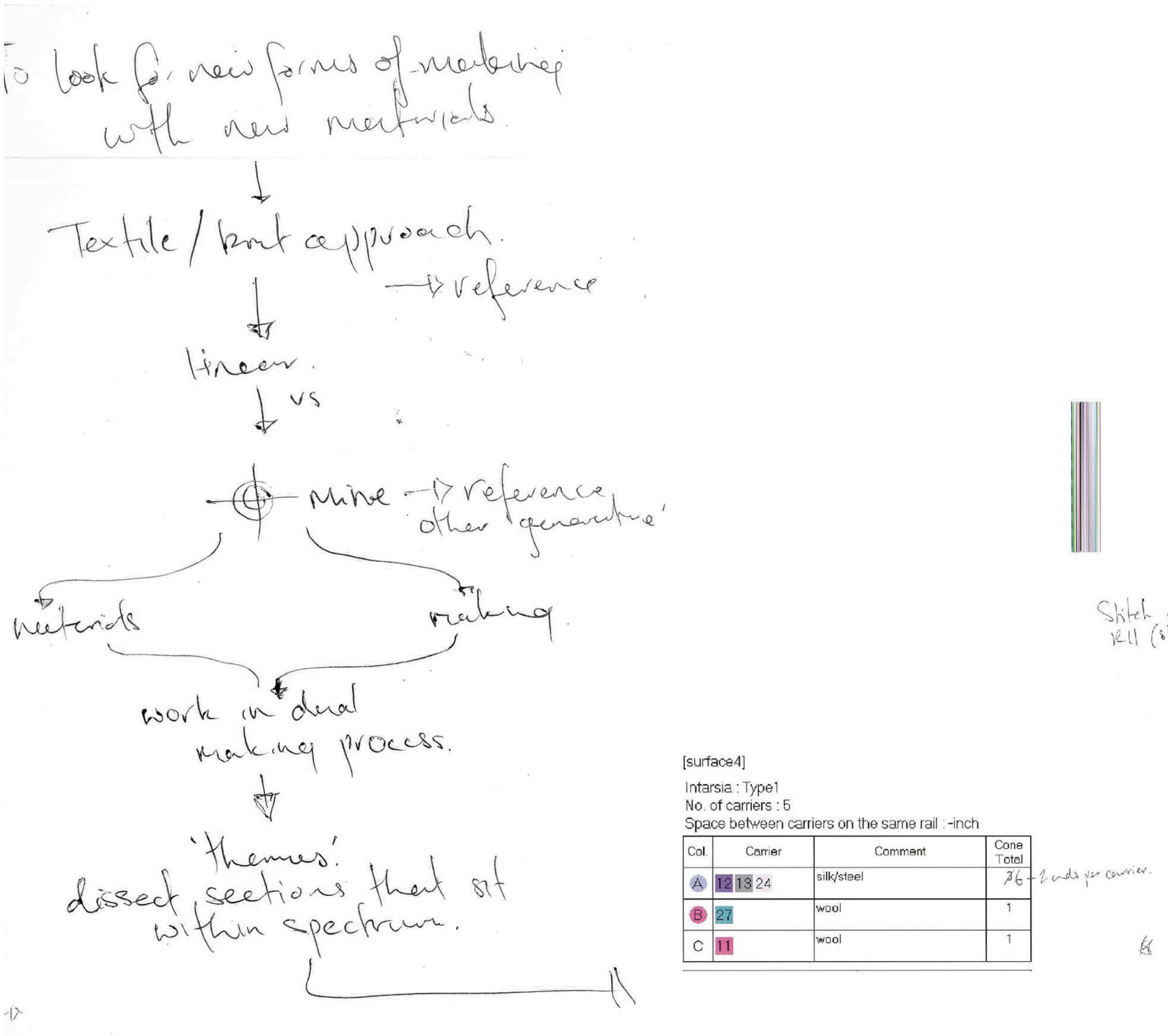


Fig 29. *Documentation in Journals*

Fig 30. *Data Sculpture Knits 11 Pemotex/Wool/Silk and Stainless Steel Reaction to Heat*

Fig 31. *Work Space*

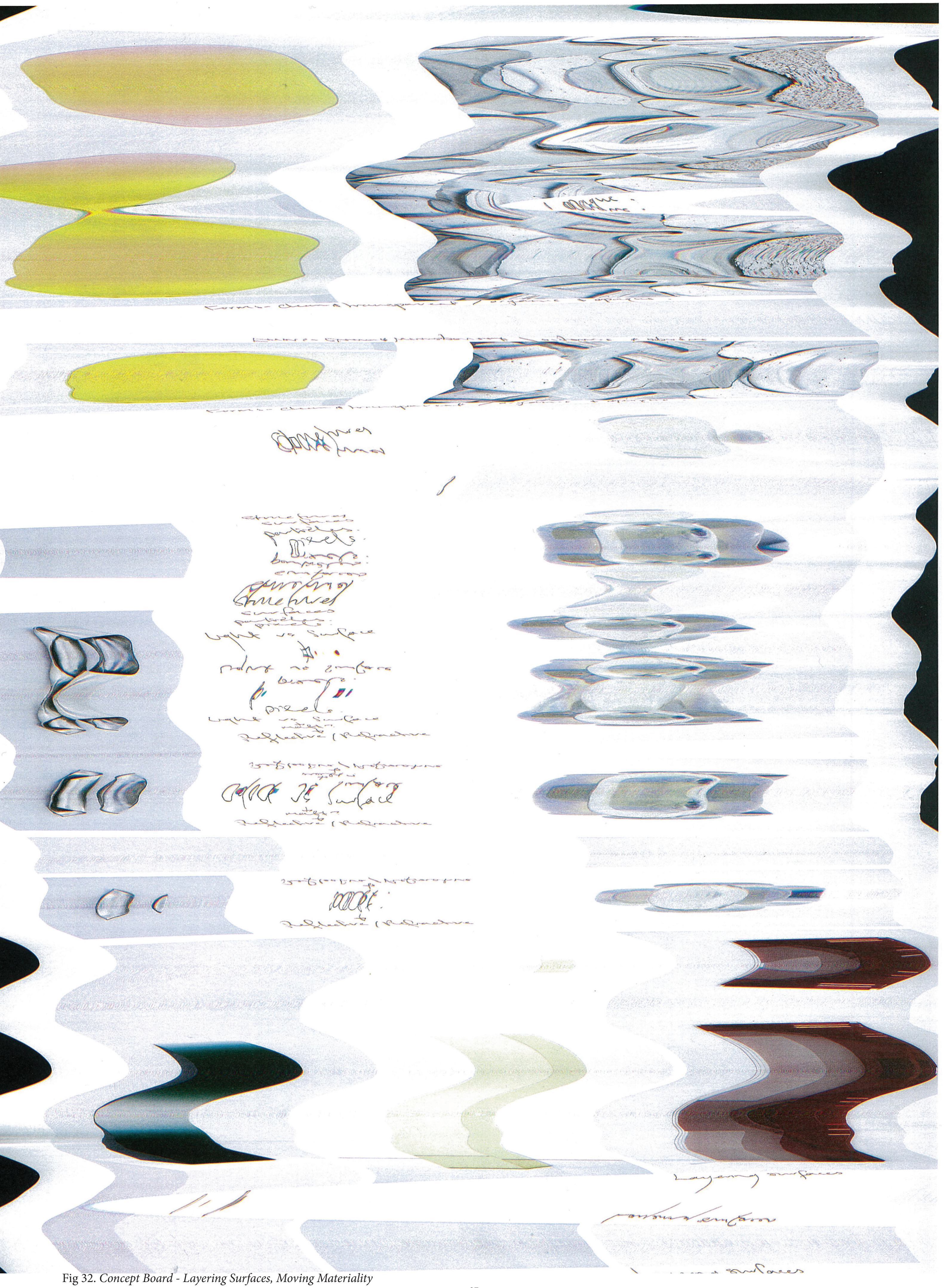


Fig 32. *Concept Board - Layering Surfaces, Moving Materiality*

The knitted samples, as well as the programming notes, data images, concept boards and mind maps all became materials interacting with one another and influencing the evolution of the practice as the designer reflected, refined and reshaped successive designs. Within the rhizomatic research approach, the process, at times, became iterative, paths of working crossing back on themselves as the interactive textiles were knitted in hybrid structures of different yarns. The iterative cycle allowed for a comparing and contrasting of Shima Seiki data files as well as conductivity readings of the textiles (refer to Appendix C). Reflective and refractive cycles of making textile samples, followed by testing, also allowed the designer to examine expressive qualities of the interactive textiles (Bergström et al., 2010; Karana, Barati, Rognoli, & Van der Laan, 2015).

Depending on programmed stitch structure and the resistance of fibres used in the design process, different samples express various behaviours through interaction. As the textile interfaces with the computer via Arduino, tangible interactions with the knit structure create effects in the programmed three-dimensional textile within Grasshopper.

5.10 Collaborating of Bodies and Forces

Expressiveness and agency manifest through a collaboration of bodies and forces (Bennett, 2010) as the digital textile responds to the physical interactions. Here materials and forces "mix and meld with one another in the generation of things" (Ingold, 2009, p. 92) as new textile structures emerge.

A framework of experimental, practice-led design research enabled the designer to work in and through ideas as they presented themselves; "crafting the aesthetics of form and temporal dynamics, recombining and tinkering with materials" (Redströem, Mazé, & Redströem, 2005, p. 45). This mode of researching enabled a dynamic practice of designing from, with and for interactive textiles through generative approaches. Making, as Ingold states (2000, p. 68), is a reciprocal process of 'becoming' between designer and material. The notion of becoming, according to Bergström et al. (2010), can be understood philosophically as the open-ended evolving and emergent "inevitable indeterminacy over future eventualities" (p. 160). This research has embraced the notion of becoming, investigating new design methods where digital and physical matter is regarded as engaged material agents in the generative modes of making with and for interactive textiles.

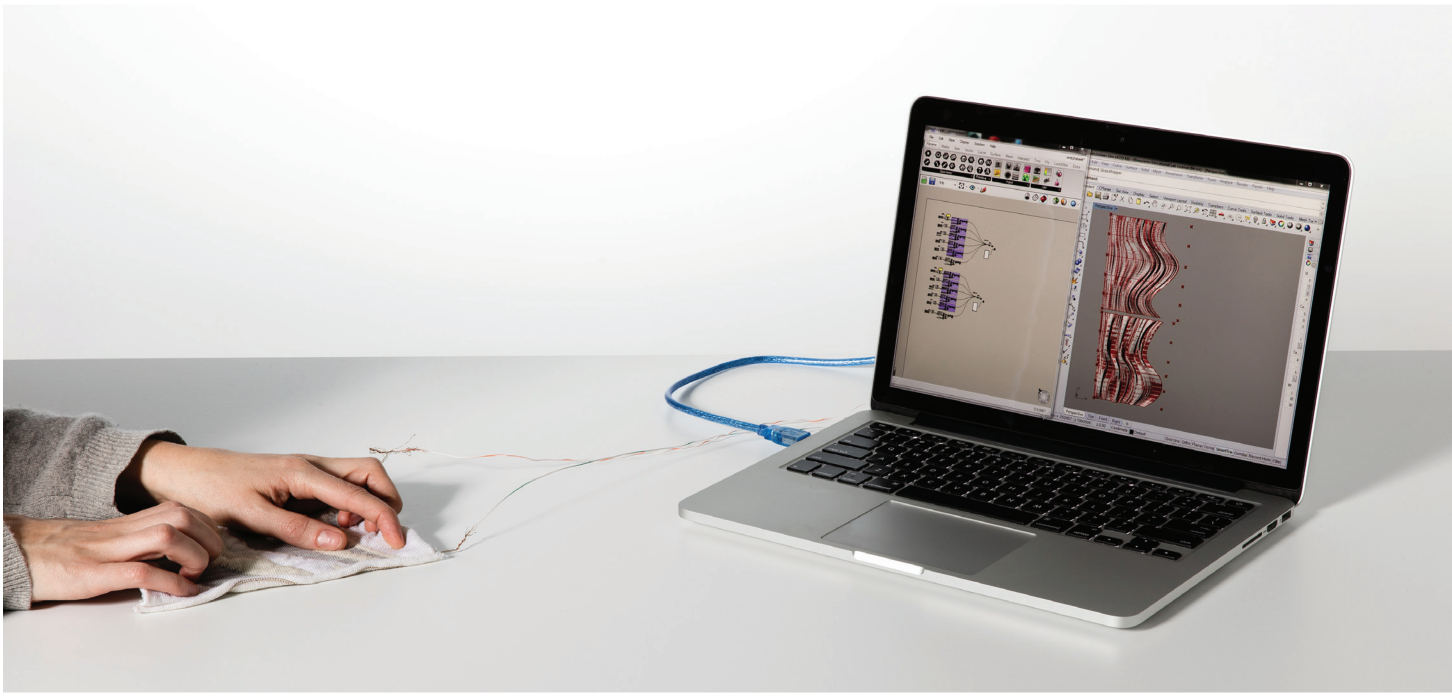


Fig 33. *Tangible Interactions*

Fig 34. *Data Knit Structures Become Tools for Further Generation*

Fig 35. *Tangible Interactions*

Fig 36. *Yarn Selection*

5.11 The Materialising of Generative Textiles

The last artefacts designed in this body of work should not be understood as 'final' pieces, but instead as textiles expressive of a generative design practice established. This section analyses the making of the artefacts exhibited for examination.

Data Cast Jacquards (Fig 37 & 38). The three-dimensionally printed Data Sculptures were scanned and the images processed into Knit-design at one for one scale. In Knit-paint each image pixel of a Data Sculpture image became a single stitch. These large scale textiles were called Data Cast Jacquard No 1, Data Cast Jacquard No 2, Data Cast Jacquard No 3 and Data Cast Jacquard No 4. After sampling smaller sections of these new knit textiles, yarns were chosen based on their properties and how they reacted against one another within the knit structure or when exposed to environmental stimuli such as heat or steam. Differing combinations of heat reactive yarns such as pemotex or heat set polyester, natural yarns and stainless steel allowed for permanent three-dimensional surfaces emerge within the knit structures on contact with heat. Data Cast Jacquards No 1 and No 2 assembled cotton, cashmere and pemotex within their structures while Data Cast Jacquards No 3 and No 4 combined stainless steel, cotton, cashmere and heat set polyester.

Knit Data Jacquards (Fig 39 & 40). As the large scale, Data Cast Jacquards were processed the knit development data was captured and saved as an images file. This development data is made up of lines of code that instruct the digital knitting machine on how to perform the knitting of each row. The image files were then generated back into knit structures to create the next generation of textiles, the Knit Data Jacquards. Each Knit Data Jacquard is encoded with the digital information for the making of each Data Cast Jacquard. In previous design stages only small sections of these captures had been tested as knitted textiles, but here large files were created to include more digital information. This process of rendering the data back into new knit artefacts allowed for structures and formations to materialise; transient and vibrant, interconnected to the Data Cast Jacquards.

Conductive Data Casts/Sensors (Fig 34.). Throughout the process of making, smaller knit swatches of the Data Sculptures were created. These were continually evolving as different sections were programmed and various yarns were incorporated into the structures. The yarns integrated into the making of these sensors included merino wool, cotton, pemotex, lycra, bamboo, seacell, linen, cashmere, silver and stainless steel. Again heat sensitive yarns were utilised to create three-dimensional forms within the knit structures, and all sensors incorporate conductive yarns such as silver or stainless steel blends to render them capable of responding to electronic currents. Depending on the combination of yarns used, these textiles display different electronic behaviours once connected to a microcontroller. Five of the Conductive Data Casts were chosen to perform as touch sensors for the Interactive Making Installation within the exhibition.

Fig 37. *Large Scale Data Cast Jaquard No 1*

Fig 38. *Detail of Large Scale Data Cast Jaquard No 1*

Fig 39. *Detail of Knit Data Jaquard No 2*

Fig 40. *Detail of Knit Data Jaquard No 4*

Fig 41. *Back view of (L-R) Data Cast No 2, Knit Data No 4, Data Cast No 1 and Knit Data No 1*

Fig 42. *(L-R) Knit Data No 1, Knit Data No 2, Knit Data No 5, Data Cast No 2*

Fig 43. *Conductive Data Casts connected to Arduino*

Fig 44. *Close up of Knit Data No 2, Knit Data No 5*

Fig 45. *Large Scale Jaquards in Exhibition*

5.12 Exhibiting Expressive Materials, Generative Textiles and Digital Matter

The final exhibition was installed in Gallery 3 at AUT. This exhibition of work, like the written exegesis, was presented as an assemblage of ideas and concepts, active and shifting. The interrelated artefacts that had emerged throughout the generative practice could be viewed as a cohesive whole.

At one end of the gallery the large-scale pieces, the Data Cast Jacquards and corresponding Knit Data Jacquards, were suspended from custom built structures through the centre of the space. These display structures allowed for a layering of the textiles in space, rendering both sides of the structures visible. The spatial structures enabled the viewer to move through, around and in-between the large scale textiles echoing their transient, vibrant and interconnected nature.

As the practice-led research project investigated generative ways of designing with interactive textiles, an Interactive Installation was created. This allowed for the viewer to become the maker and engage in their own experience of generating form through interactive materials. The installation, presented at the opposite end of the space, reflects back at the large scale knitted textiles. The parameters of the previously developed Grasshopper algorithm were utilised, but the final design of the programming was advanced and refined.

In Grasshopper the lines or 'threads' of visual code that affect the structure of the 'digital textile' in Rhino became representative of five different Data Knit Sensors; these sensors have their own electronic behaviours which are dependable on the combination of conductive and natural yarns utilised in the knitting process. The Grasshopper file also allowed for real-time simulations where physical interaction with the Conductive Data sensors could generate a continually changing digital artefact. A large screen was set up to project the digital textile within the Rhino interface; this allowed for the maker to observe how their interactions with the data sensors could craft a new screen based textile. The design process becomes one of collaboration between maker, active materials and self-assembling matter. The maker and the interactive textiles become contributors to the creative process where the emergence of transient, vibrant screen based textiles can at any time be 'captured' and generated into a new knit structure.

Chapter 6. Conclusion

An assemblage of concepts exploring making, matter, materials, forces and bodies present new perspectives that challenge how we conceive textiles and how we can engage with them as collaborating agents in the design practice. Along the rhizomatic trajectory of making, at any point in the process, the textile surface becomes ingrained with new meaning, and the ability to express new emergent qualities.

This research establishes a fluid, non-linear practice where outcomes are undefined, allowing for openness in the making process. Textile artefacts are simultaneously both tool and material to design with, and emerge through co-agency interventions. By diverging from established rules and disrupting a linear textile practice, issues of interactive and embodied making give rise to new processes where interactive textiles emerge. The research bridges material agency and generative methodologies to explore new modes of making using the medium of textile knit.

Investigations evolved from the behaviour of conductive stitch structures to more complex and meaningful artefacts. Knitted textile structures have emerged through a generative process of digital and physical interactions and are ingrained with encoded matter. The artefacts manifest in an 'indeterminate and complex choreography of matter' (Coole & Frost, 2010 pp. 7–9) within structure and surface. Critically, in this design process, they have the dexterity to perform as tangible textile interfaces between physical and digital spaces as they can respond to touch and interaction and have the potential to generate dynamic three-dimensional simulations once again. Through real-time digital simulations, the artefacts and designer (or other bodies) co-emerge in generative processes where shifting and becoming materials can be realised. Designing with generative algorithms becomes a means of transforming physical interactions back into data and digital matter for further generation of textiles structures. Each generative step has defined notions of agency, materiality and interactivity, from a practical and theoretical perspective to establish a new design methodology for making interactive textile structures.

This research advances knowledge around new modes of making where materials and digital data are considered dynamic and active in the design process and contribute to the generating of new textile structures. By embracing a practice such as this, new processes of generating textiles in and for the design field emerge. A methodology such as this is not limited to textile applications and has the potential to expand other areas of design and digital making.

Fig 46. *Large Scale Jaquards in Exhibition*

Fig 47. *Detail of Screen and Sensors Interactive Installation in Exhibition*

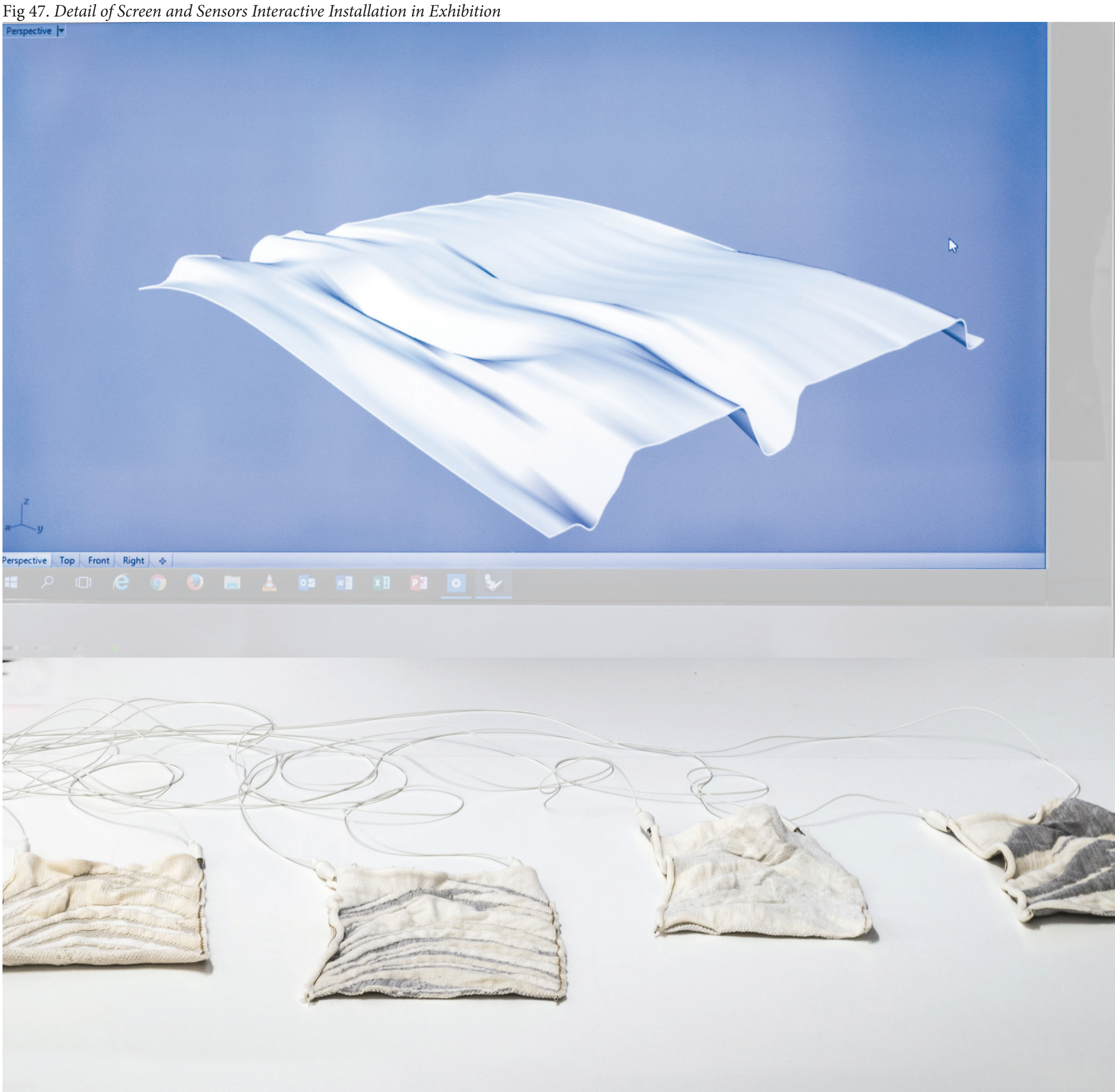


Fig 48. *Detail of Knit Data Trail.*

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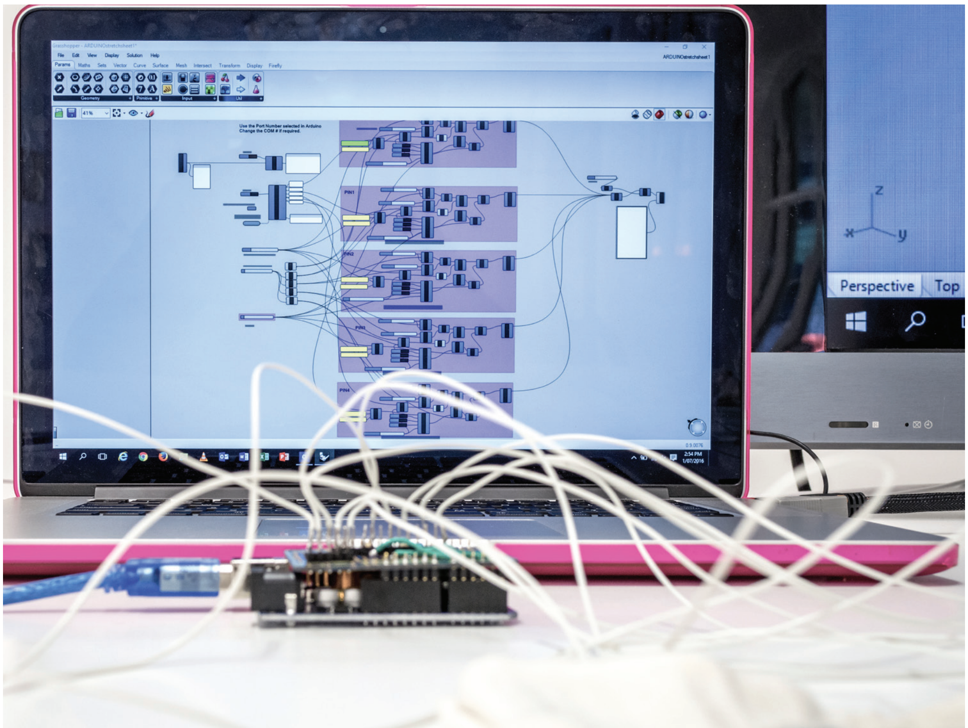

Fig 49. *Detail of programming for Interactive Installation in Exhibition*

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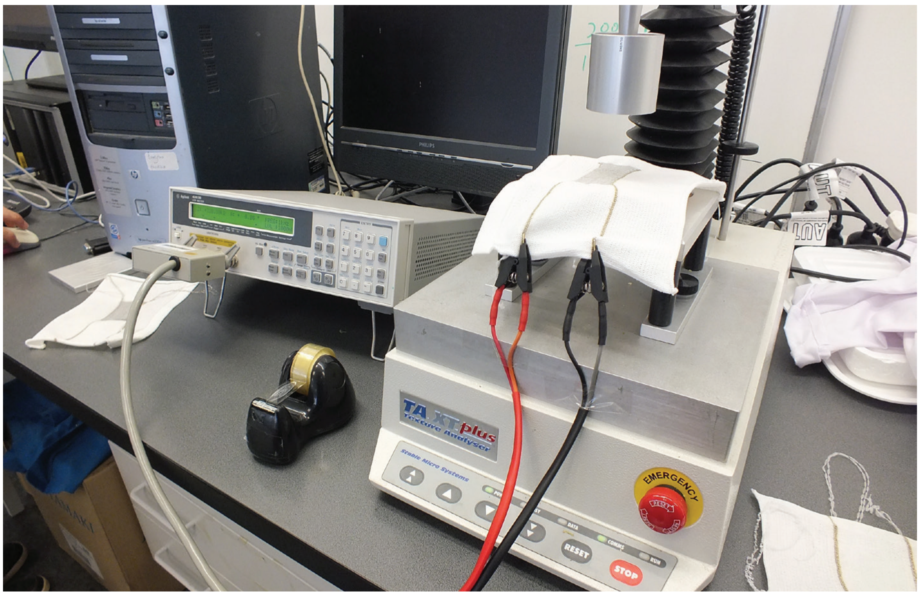
Appendices

Appendix A

A Conductive Knit Structure Investigation

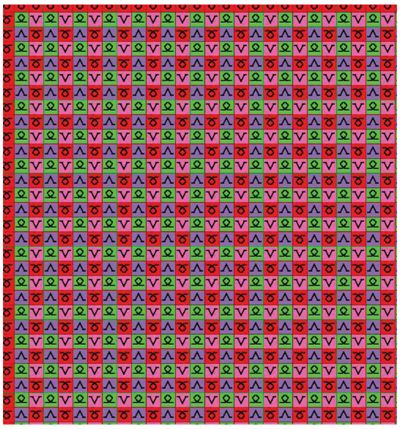
An investigation into conductive knitted structures. This sample book was an early collaborative project between Hollee Fisher and Caroline Stephen. The parameters were set by conductive yarn used, the size of the conductive patch in terms of courses and wales, and the surrounding based fabric. The variable of each sample was the knitted structure used for constructing the conductive area. Stitch structures which varied between a combination of purl, tucks and double knits were explored.

These conductive samples underwent testing to investigate the resistive capability of different stitch structures and their repeatability. This testing was carried out alongside Master of Engineering student Yasir Al-Hilali. All technical knit structure visualisations in the following appendices have been generated via the Shima Seiki programming system, KnitPaint.

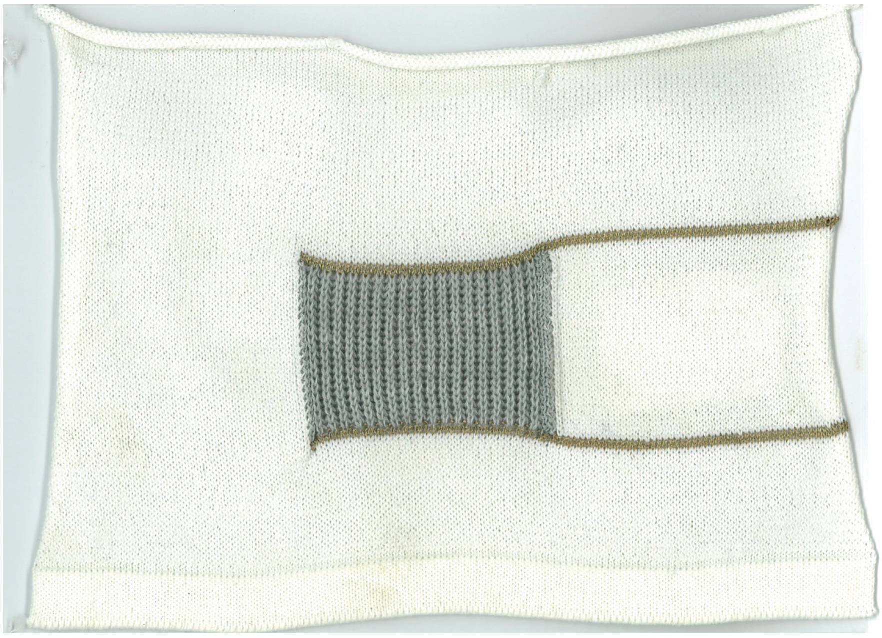


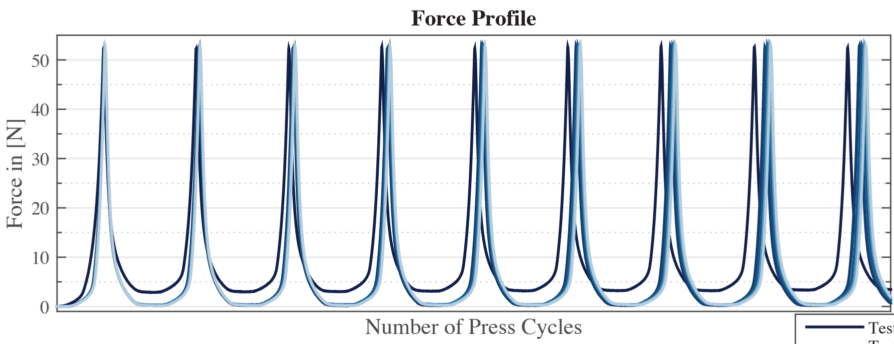
Sensor Testing Setup

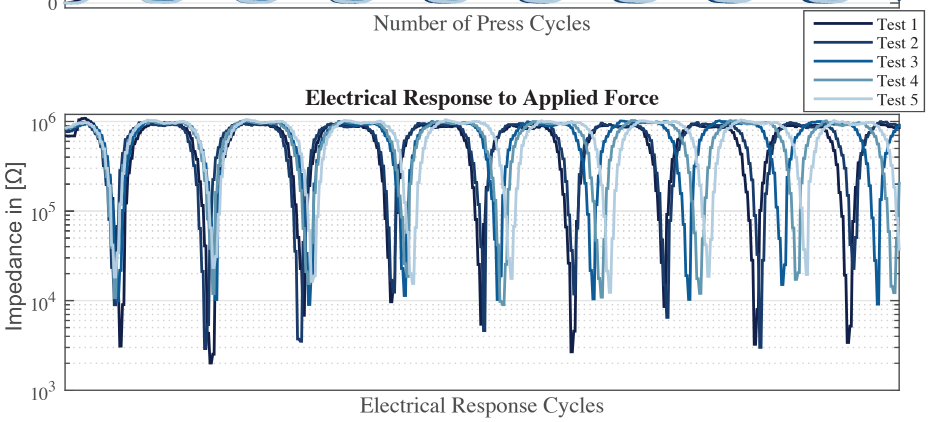
Appendix A



Stitch: Full Cardigan

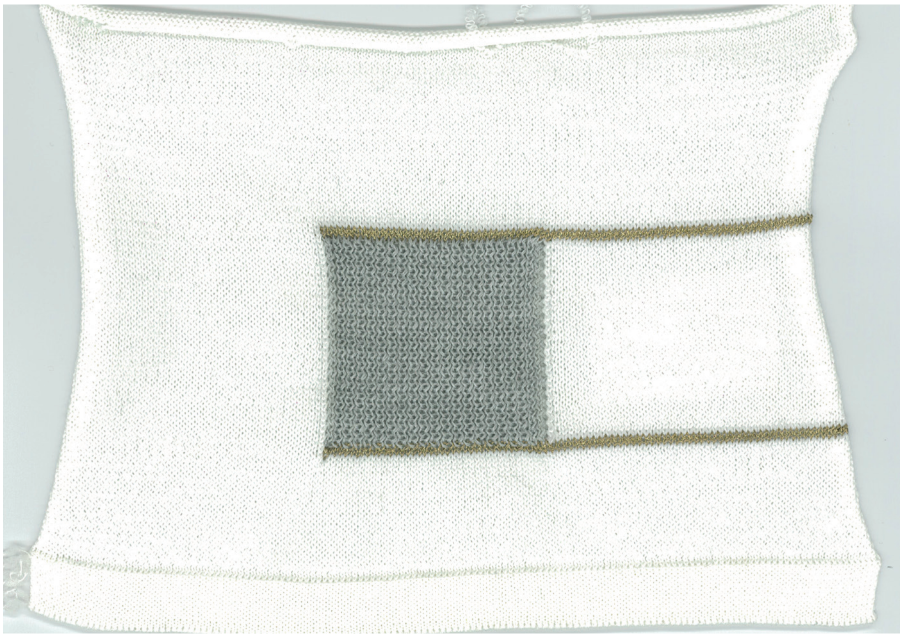


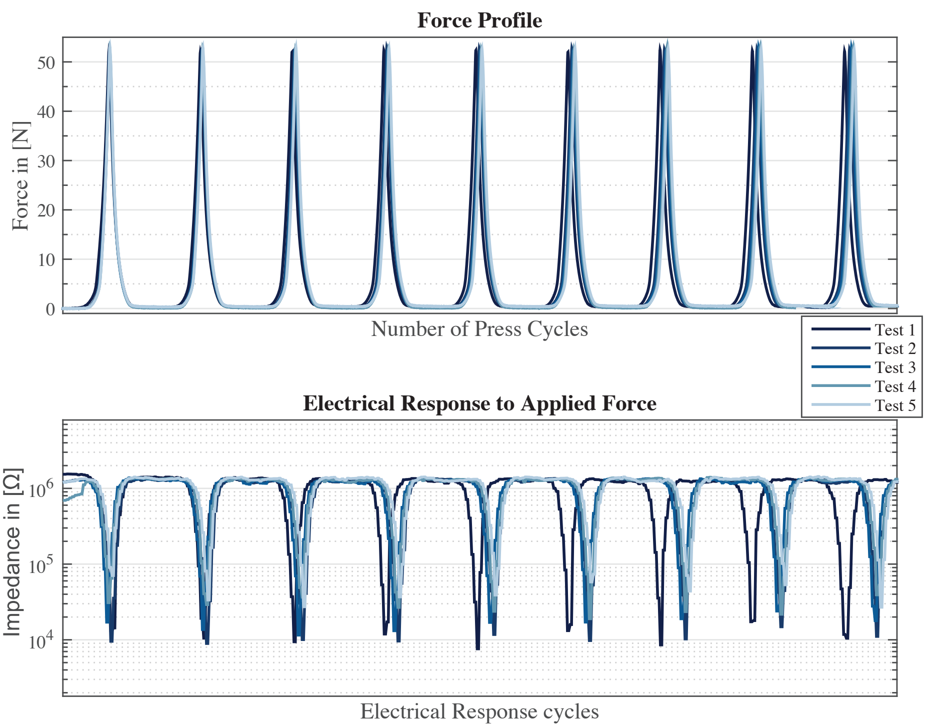




Appendix A

Stitch: 1x1 Rib





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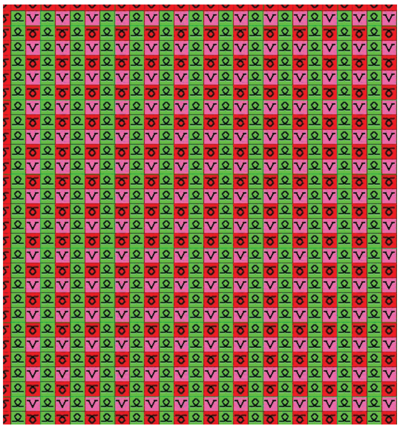
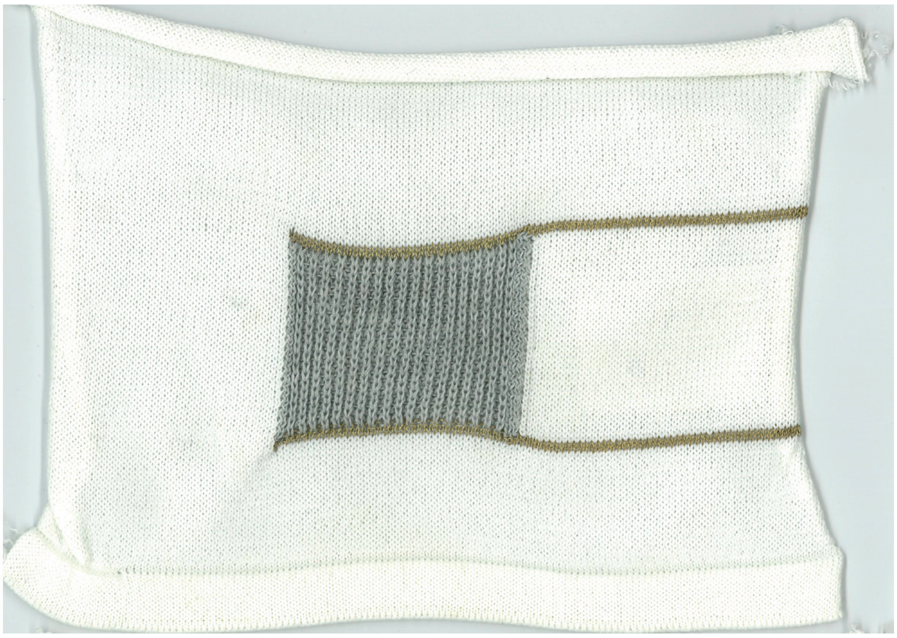
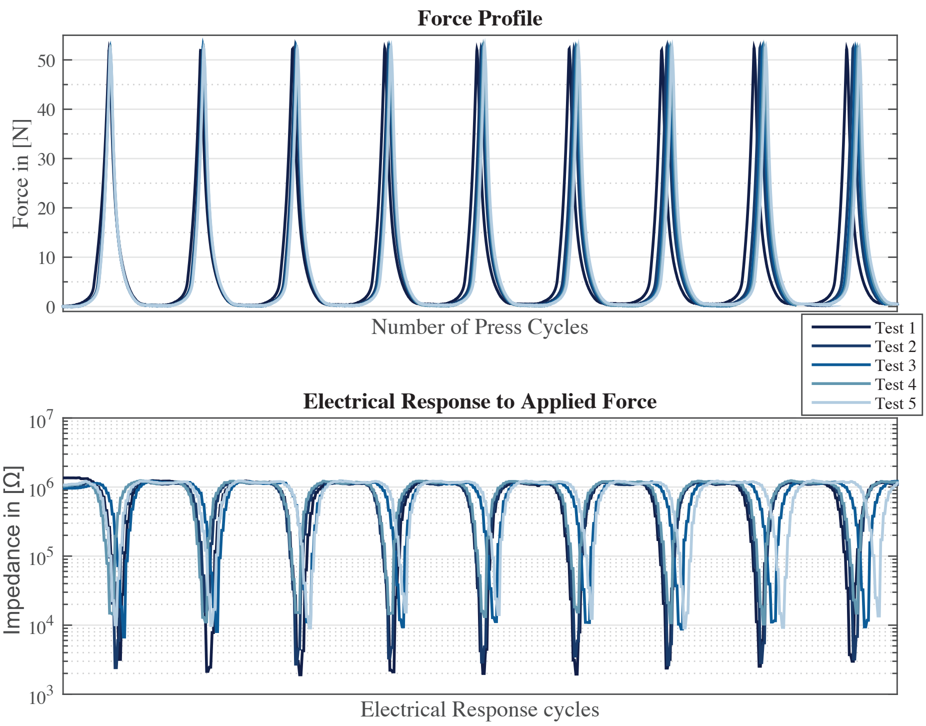


Stitch: Half Cardigan





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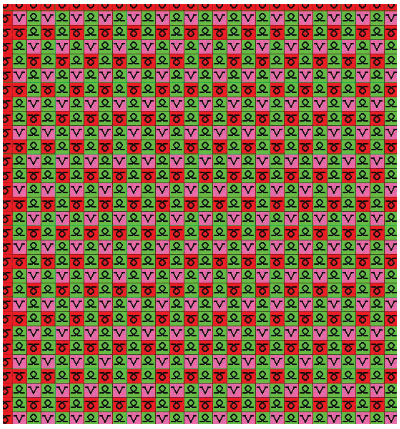
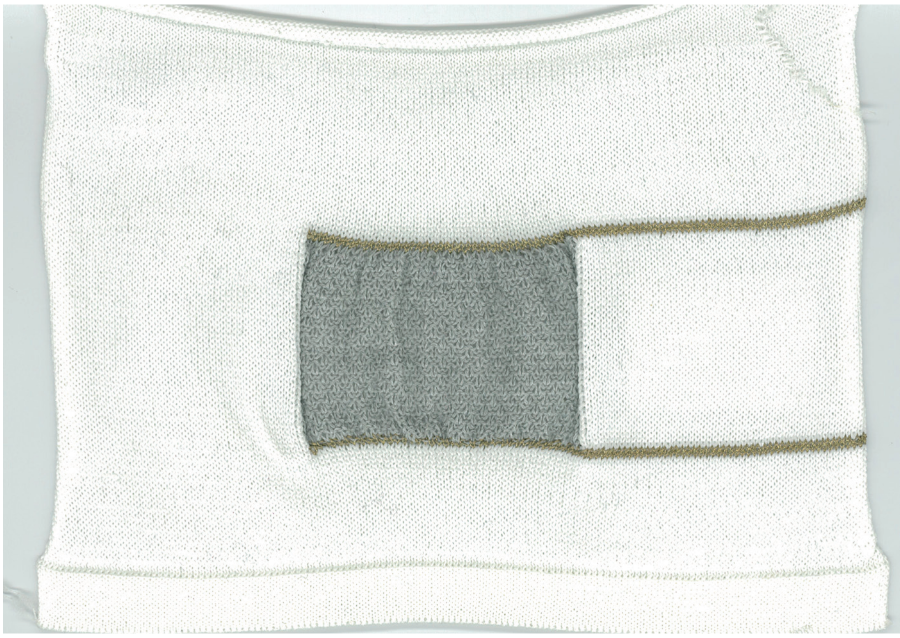
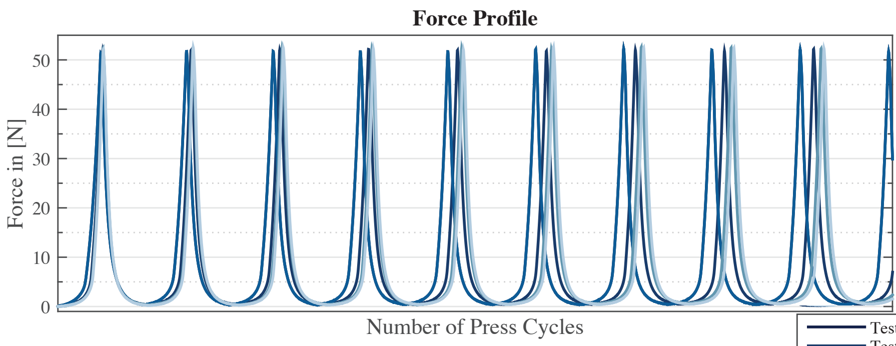
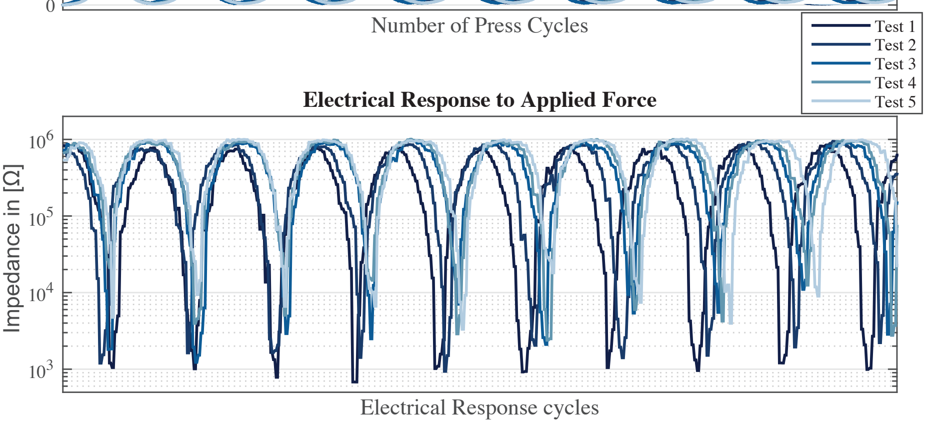


Stitch: Tuck v1







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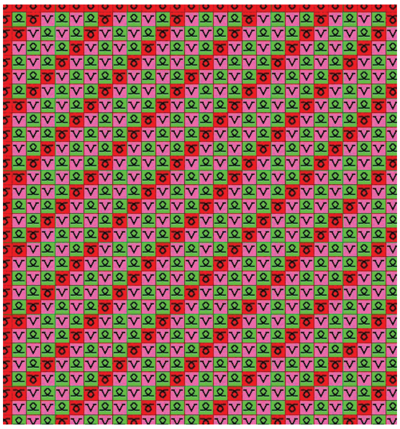
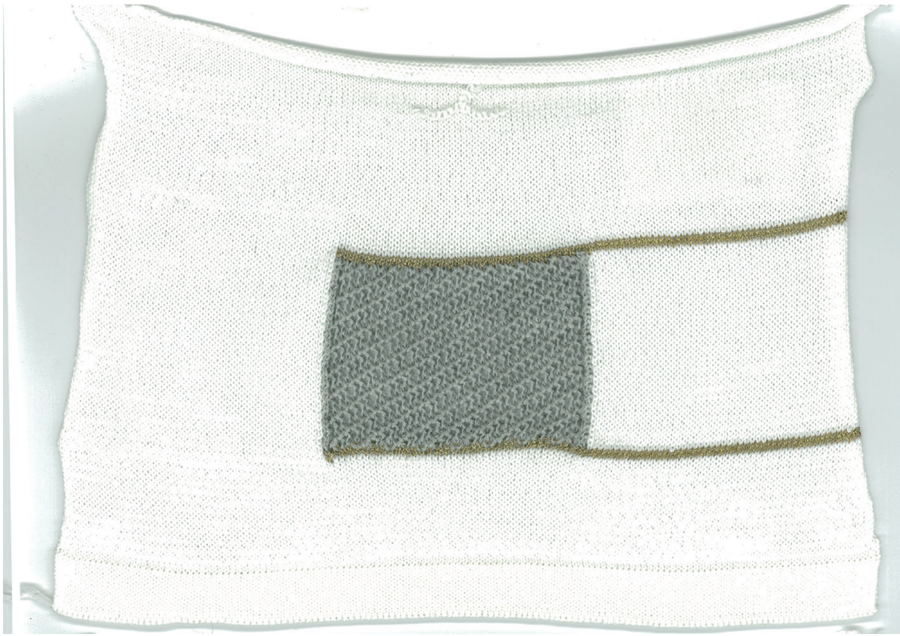
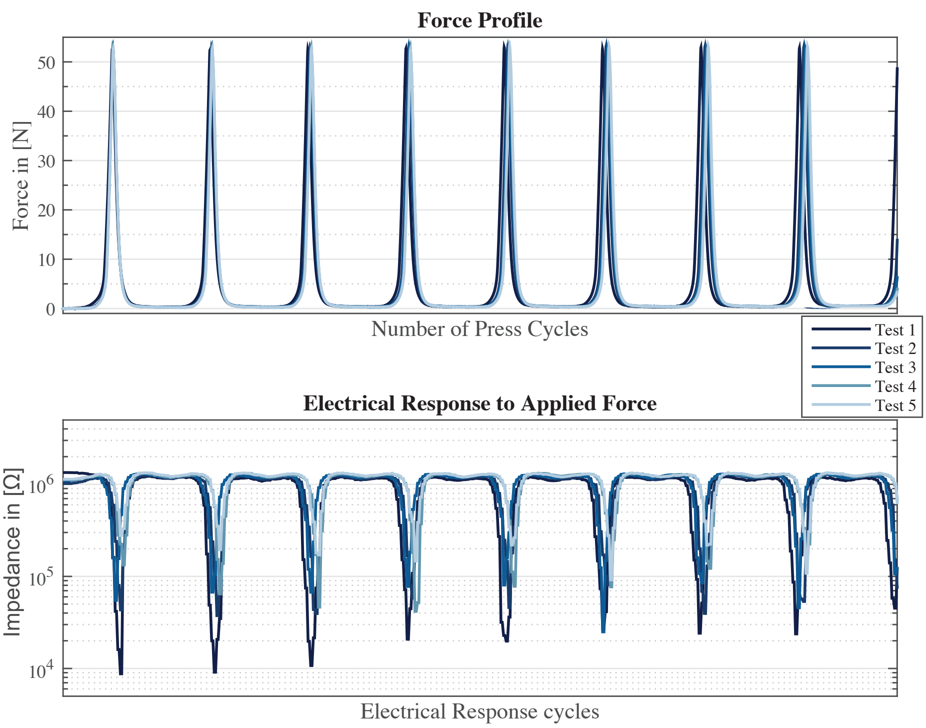
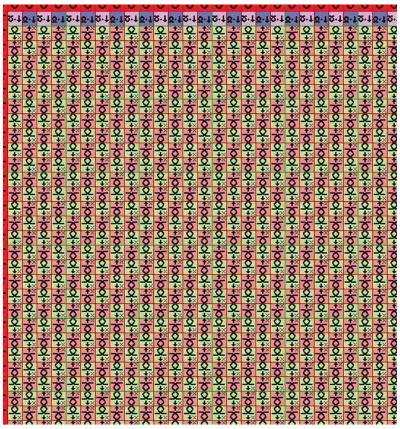


Stitch: Tuck v2

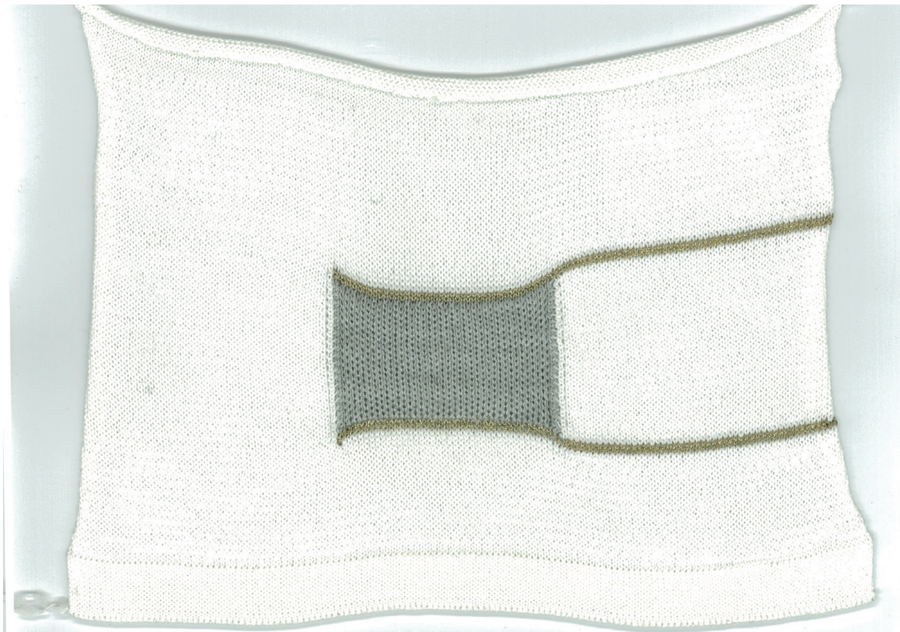


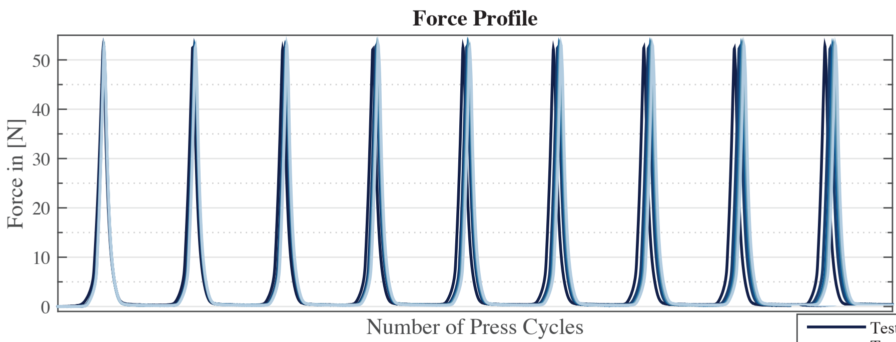


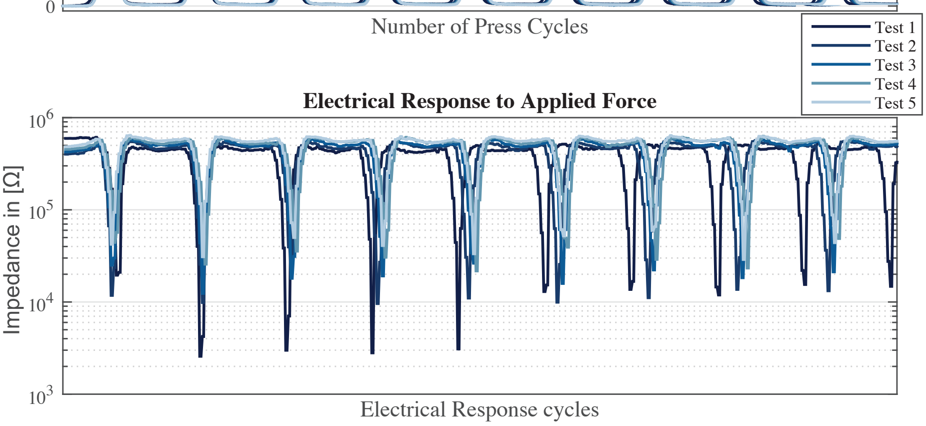
Appendix A



Stitch: Interlock







Appendix B

A Materials Library

Designing through exploration of emerging textiles and their inherent functions and properties drives innovation. There is potential for the growth of knowledge around new textile materials across multiple disciplines and practices.

Yarn/Fibre Name	Tasman Merino Wool
Company	Di.Vé Italy
Weight	2/28 Nm
Fibre Content	100% Merino Wool
Extra Notes	Di.Vé yarn can be ordered in small quantities from DEA Yarn http://www.deayarns.co.nz/dve-home.htm
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	1 end of 2/28 Nm
Loop	6
Stitch	46
Construction Notes	-
Material Properties and Potential Applications	Like all 100% wool fibres Merino is natural and renewable. A wool fibre is composed of a natural protein called keratin that is biodegradable. Merino wool fibres are very fine, making them more flexible than coarser wool fibres. This flexibility gives Merino wool a notably soft handle. Merino wool has long been used as a fibre for construction of high quality garments but substantial research shows the multitude of benefits of wool. There is a lot of research currently underway around the benefits of Merino wool and medical uses [1]. Wool's inherent chemical structure makes wool naturally flame resistant and Merino wool clothing provides good protection from the sun, compared with the protection from other fibres.

Yarn/Fibre Name	Pasubio Alpaca Wool
Company	GTI Filati Italy
Weight	2/50 Nm
Fibre Content	100% Alpaca Wool
Extra Notes	GTI Filati yarn can be ordered in small quantities from DEA Yarn http://www.deayarns.co.nz/gti-home.htm
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	1 end of 50/2 Nm
Loop	5.60
Stitch	46
Construction Notes	-
Material Properties and Potential Applications	Alpaca wool fibre is similar in structure to sheep wool fibre, although compared to wool of similar fineness, alpaca has shown to be higher yielding, more heavily medullated (hollow pockets in the fibres), longer, and considerably stronger. The individual scales on the shafts of alpaca fibres are smoother and lower than those on the fibres of other mammals, resulting in a very soft fabric. Alpaca has unique thermal properties due to the microscopic air pockets found in the fibre, creating greater thermal capacity than almost any other animal fibre. Alpaca fibres have a higher tensile strength compared to other wool fibres, the average tensile strength of alpaca is 50 N/ktex and has a score of 15,000 cycles of abrasion, making the yarn suitable for upholstery. It does not retain water, is thermal even when wet and can resist solar radiation effectively. Because Alpaca fibre contains no or very little lanolin it is hypo-allergenic.

Yarn/Fibre Name	Wool Crepe S Twist
Company	The Yarn Purchasing Association
Weight	30/1 Nm
Fibre Content	100% Wool
Extra Notes	-
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	2 ends
Loop	5.60
Stitch	46
Construction Notes	As these yarns have a high twist care needs to be taken when knitting as yarn can tangle on cone.
Material Properties and Potential Applications	Yarn is created during the spinning process where multiple individual fibres are aligned and twisted together. Twist is inserted in a yarn in either a clockwise (Z), or anticlockwise (S) direction, producing yarns with directional properties. Conventional yarns are engineered to have balanced properties, by folding or plying ends together [2]. Crepe yarns have a high twist of 800-1000 turns per metre. In combination with the natural moisture absorbing properties of wool being a protein fibre, when steamed the knitted fabrics will turn either left or right depending on whether the yarn is S or Z twisted. This can result in interesting shaping in knit structures.

Yarn/Fibre Name	Wool Crepe Z Twist
Company	The Yarn Purchasing Association
Weight	30/1 Nm
Fibre Content	100% Wool
Extra Notes	-
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	2 ends
Loop	5.60
Stitch	46
Construction Notes	As these yarns have a high twist care needs to be taken when knitting as yarn can tangle on cone.
Material Properties and Potential Applications	Refer to Wool Crepe S Twist

Yarn/Fibre Name	Eco Verde
Company	Coats
Weight	tex 80
Fibre Content	100% Organic Cotton
Extra Notes	Eco Verde is produced as a sewing thread but has the potential to be used in knit construction also.
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	1 end
Loop	6
Stitch	46
Construction Notes	-
Material Properties and Potential Applications	Coats Eco Verde sewing thread is made from the best quality organic Giza cotton staple fibre. Organic cotton is generally understood to be grown from non genetically modified plants, without the use of any synthetic agricultural chemicals such as fertilizers or pesticides. Its production also promotes and enhances biodiversity and biological cycles. Being mercerised Coats Eco Verde is treated under tension to provide high lustre and strength.

Yarn/Fibre Name	SeaCell
Company	The Yarn Purchasing Association
Weight	27/2 Nm
Fibre Content	75% Supima Cotton 25% SeaCell
Extra Notes	-
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	1 end
Loop	6
Stitch	46
Construction Notes	-
Material Properties and Potential Applications	This yarn is a blend of 75% combed cotton with long fibres and 25% SeaCell. SeaCell is a cellulose fibre, produced through the lyocell process, which is an environmentally sound production method. Antibacterial test results show that good antibacterial activity can be obtained even by small percent of SeaCell Active fibres [3].

Yarn/Fibre Name	Ramie
Company	Habu Textiles
Weight	2/30 Nm
Fibre Content	100% Ramie
Extra Notes	Although very strong, ramie can be brittle. Try winding onto a new cone so the yarn runs through wax.
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	1 end
Loop	5.60
Stitch	46
Construction Notes	Ramie proved difficult to knit, and although knitting was more successful after running the yarn through wax, care needed to be taken when knitting. As the yarn is brittle and has little elasticity steps can be taken to put less stress on the yarn during knitting process. The knitting speed was lowered considerably and the yarn was not around the encoder to knit this swatch.
Material Properties and Potential Applications	Ramie (Boehmeria nivea) is a bast fibre crop belonging to the Urticaceae or Nettle family. It is one of the oldest textile fibres, having been used for at least six thousand years, and is principally used for fabric production. Advantages of Ramie include luster, strength, excellent microbial resistance and valuable hygienic properties [4]. Ramie fibre is very durable; depending on the method of processing the fibre it can have a tensile strength eight times that of cotton and seven times greater than silk. Ramie increases in strength when wet. Ramie is resistant to bacteria and mildew, and is extremely absorbent. The 100% Ramie fibre withstands high water temperatures during laundering, maintains its shape and is shrink resistant. Disadvantages of Ramie include its low in elasticity and low abrasion resistance. Ramie fabric can also be stiff and brittle. Unlike other bast crops, ramie requires chemical processing to degum the fibre and the production of the yarn is very labour intensive.

Yarn/Fibre Name	Pineapple Ramie
Company	Habu Textiles
Weight	
Fibre Content	60% Pineapple, 40% Ramie
Extra Notes	Try winding onto a new cone so the yarn runs through wax.
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	1 end
Loop	5.60
Stitch	46
Construction Notes	Like 100% Ramie this yarn was difficult to knit. Refer to notes for Ramie. Wind onto new cone so that yarn runs through wax. Tighten knot catcher to stop the machine before slubs are knitted. These slubs cause holes in knit. Again lowering speed proved helpful.
Material Properties and Potential Applications	The pineapple leaf fibre is taken out from the vein of the pineapple leaves and Ramie is added for an additional strength and durability in the yarn. Pineapple leaf fibre is rich in cellulose, relatively inexpensive and abundantly available. The use of lignocellulosic fibres such as pineapple leaf fibre (PALF) and sisal as reinforcements in thermoplastic and thermosetting resins for developing low cost and lightweight composites is an emerging field of research in polymer science and technology. While these fibres may not be as strong as carbon and Aramid, their main advantages are low cost and biodegradability. The cellular structures of the plant fibres also provide excellent insulation against heat and noise. Further, most cellulosic fibres are harvested yearly and the supply should be inexhaustible compared to the limited supply of the oil reserve from which many synthetic fibres are derived [5] & [6].

Yarn/Fibre Name	Natural Bamboo Yarn
Company	Loro Piana S.p.a.
Weight	2/36 Nm
Fibre Content	100% Natural Bamboo
Extra Notes	This yarn can be sourced through Uppingham Yarns.
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	1 end
Loop	6
Stitch	46
Construction Notes	-
Material Properties and Potential Applications	Bamboo fibre is a regenerated cellulosic fibre made from starchy bamboo pulp. Further chemical processes produce bamboo fibre. Bamboo fibres have unique properties such as natural antibacterial, UV-shielding and moisture-controlling characteristics. Bamboo is softer than cotton, and because the cross-section of the fibre is filled with various micro-gaps and micro-holes, it has better moisture absorption and ventilation. Moisture absorbency is twice than that of cotton. Test results showed that bamboo has a strong antibacterial effect and bamboo has significantly higher UVB blocking efficiency than cotton [7]. Potential applications include medial and healthcare textiles as well as clothing for summer and outdoor wear. This natural bamboo yarn has a slightly rough and heavy handle.

Yarn/Fibre Name	Bamboo Single Yarn
Company	Habu Textiles
Weight	
Fibre Content	100% Bamboo
Extra Notes	-
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	2 ends
Loop	6
Stitch	46
Construction Notes	The knitted swatch is slightly uneven. This could be caused by twist is the yarn.
Material Properties and Potential Applications	Refer to notes from Natural Bamboo Yarn. This bamboo yarn swatch is much finer, softer and has a silky feel and beautiful drape.

Yarn/Fibre Name	Bamboo & Copper
Company	Habu Textiles
Weight	20/1
Fibre Content	67% Bamboo, 33% Copper
Extra Notes	-
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	1 ends
Loop	5.60
Stitch	46
Construction Notes	Knit on slower speed and without utilising encoder to insure yarn does not break or tangle.
Material Properties and Potential Applications	This yarn has the properties of both Bamboo and Copper. This hybrid yarn can be used to create 3D form in the knit structure due to the shape forming capabilities of the fine copper wire. Metallic wires and fibres are being created to develop conductive yarns for sensors, transmitters and EMI shields and copper wires can be incorporated as conductive fillers into knitted structure. Metal – Copper (Cu) Density [kg/dm3] - 8.9 Breaking strength [N/mm2] approx. from 260 to 320 Elongation [%] from 10 to 35 Copper wire is generally softer than stainless steel wire, this may be the reason this hybrid Bamboo and Copper yarn knitted with some ease. Copper wire can take shape easier compared to many metals [8], and this knitted swatch shows less curling behaviour and more stable structure than other yarns such as stainless steel blends (refer to following pages).

Yarn/Fibre Name	Linen & Stainless Steel
Company	Habu Textiles
Weight	31/1
Fibre Content	83% Linen, 17% Stainless Steel
Extra Notes	-
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	1 end
Loop	5.60
Stitch	46
Construction Notes	Wind yarn onto new cone so that yarn runs through wax. Tighten knot catcher to stop the machine before slubs (possibly in linen) are knitted. Knit on slower speed and without utilising encoder to insure yarn does not break or tangle.
Material Properties and Potential Applications	This yarn has the properties of both Linen and Stainless Steel. Linen is a natural cellulosic fibre, obtained from the stalk of flax plants. The main advantages of Linen include its low cost, it is a renewable resource and is biodegradable. The main physical properties of linen fibres include its tensile strength, high moisture absorption and low thermal resistance. Linen is a strong fibre, it has a tenacity of 5.5 to 6.5 gm/den [9]. Linen has high moisture absorption and low thermal resistance, this is why 100% linen garments are effective in hotter temperatures. Because of the Stainless Steel this hybrid yarn can be used to create 3D effects in the knit structure and because Stainless Steel is conductive this yarn could be used for sensor development and smart textile purposes.

Yarn/Fibre Name	Silk & Stainless Steel
Company	The Yarn Purchasing Association
Weight	82/2
Fibre Content	65% Silk, 35% Stainless steel
Extra Notes	-
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	2 ends
Loop	5.60
Stitch	46
Construction Notes	Knit on slower speed and without utilising encoder to insure yarn does not break or tangle.
Material Properties and Potential Applications	This yarn has the properties of both Silk and Stainless Steel. Silk is a natural protein fibre, composed mainly of fibroin and is obtained from the cocoons of the larvae of silkworms. Silk is one of the strongest natural fibres, although will lose up to 20% of its strength when wet. It has a good moisture regain of 11%. Silk has poor elasticity, therefore if elongated even a small amount, it remains stretched. Silk is a poor conductor of electricity. As the Stainless Steel in this hybrid yarn has shape forming abilities it can be used to create 3D effects in the knit structure.

Yarn/Fibre Name	Ultra Fine Stainless Steel
Company	Habu Textiles
Weight	40 micron
Fibre Content	100% Stainless steel
Extra Notes	-
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	2 ends
Loop	5.60
Stitch	46
Construction Notes	This yarn proved to be the hardest to knit. Knit on slower speed and without utilising encoder to insure yarn does not break or tangle.
Material Properties and Potential Applications	Stainless Steel textiles are used for multiple applications including medical devices, air and water filtration, protective clothing and active wear. Although Stainless Steel is a relatively poor conductor of electricity (lower electrical conductivity than copper) this yarn could be used for sensor development and smart textile purposes.

Yarn/Fibre Name	S-Shield Polyester (PET) & Inox steel fibre
Company	Schoeller Spinning Group
Weight	Nm 50/2
Fibre Content	80% Polyester, 20% Inox steel fibre
Extra Notes	-
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	2 ends
Loop	6
Stitch	46
Construction Notes	-
Material Properties and Potential Applications	Long-staple polyester fibres are blended with high-quality steel fibres. These steel fibres produces a constant electrostatic and/or electromagnetic screening property in the textiles. This yarn has been successfully integrated into knit structures along with Shieldex® 117 to create knit sensors.

Yarn/Fibre Name	Silver plated Nylon Conductive Thread
Company	LessEMF
Weight	22/3
Fibre Content	Silver plated Nylon
Extra Notes	-
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	2 ends
Loop	5.60
Stitch	46
Construction Notes	Conductive Thread is produced as a sewing thread but has the potential to be used in knit construction also. Care needs to be taken when knitting as thread is on a spool not a cone.
Material Properties and Potential Applications	This is a highly resistive (<1000 Ohm/10cm) [10] silver plated thread. The conductive thread is polyester with silver and is conventionally made for sewing applications. It can, however, also be knitted on knitting machines. The conductive thread is uninsulated making it excellent to connect electronic components to each other or to other electro-textiles.

Yarn/Fibre Name	Shieldex® 117/17
Company	Statex
Weight	Yarn count silverized 293 ± 2 dtex
Fibre Content	Polyamide 6.6 filament yarn. 99% pure Silver
Extra Notes	-
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	2 ends
Loop	6
Stitch	46
Construction Notes	-
Material Properties and Potential Applications	This is a filament yarn, with a silver coating. Tenacity> 35cN/tex Elongation (break) average 24% Resistivity <2k Ohm/m [11]. This yarn has been successfully integrated into knit structures along with S-Shield Polyester to create knit sensors. Statex plated fibres allow for static discharge when incorporated into antistatic carpet systems, clothing as well as clean room and medical clinic environments. When used in products manufactured to military standards, Statex fabrics prevent detection by infra-red and radar. Applications include protection clothing, tents, radar reflection and radiating antenna [12].

Yarn/Fibre Name	SwicoSilver Plasma Silver coated Polyester
Company	Tersuisse via Swicofil
Weight	dtex 125 f 36 2ply
Fibre Content	Plasma Silver coated Polyester
Extra Notes	-
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	2 ends
Loop	5.60
Stitch	46
Construction Notes	Plasma silver coated thread is produced as an embroidery thread but has the potential to be used in knit construction also. Care needs to be taken when knitting as thread is on a spool not a cone and the thread has a high twist.
Material Properties and Potential Applications	Plasma silver coated yarns tend to be higher quality and more precise than other coated yarns. The thread has a resistivity1.1 Ohms/cm. This thread was developed for embroidery applications, but can be used on knitting machines. The conductivity of these yarns can be engineered on request through Swicofil. The coating is very thin to ensure that the final product still has a textile touch.

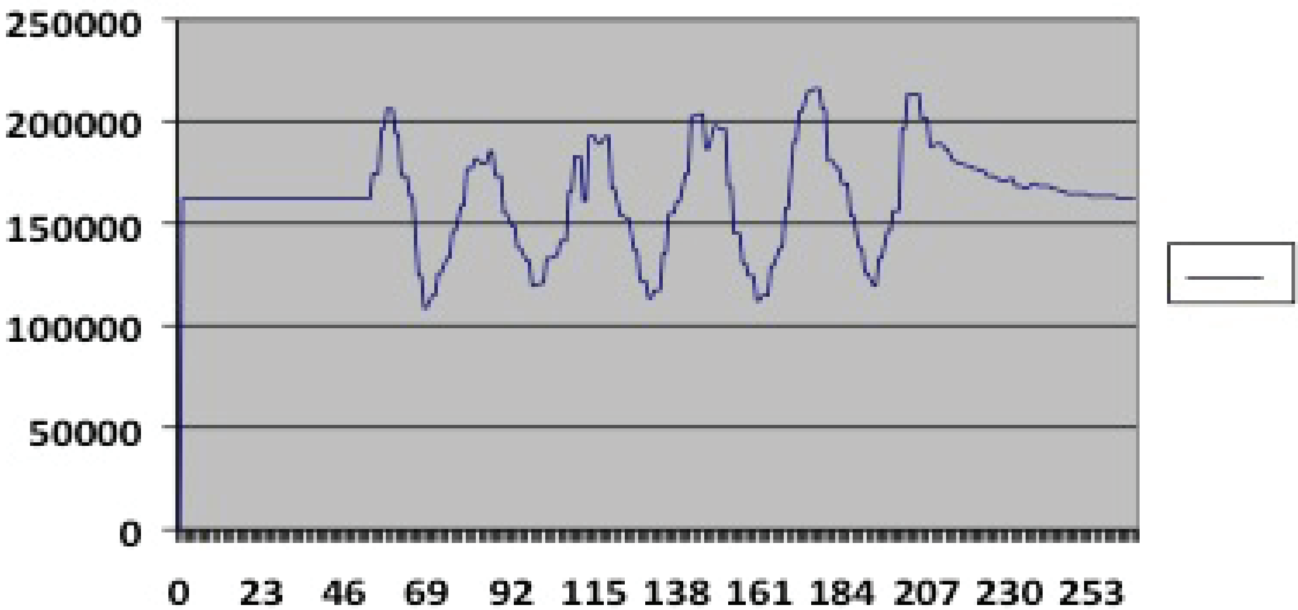
Yarn/Fibre Name	Pemotex
Company	The Yarn Purchasing Association
Weight	Dtex 850 / Nm 11.7
Fibre Content	100% Polyester
Extra Notes	-
Swatch Construction	Knit
Machine Used	14 gauge SIG machine
Quantity	1 end
Loop	5.60
Stitch	46
Construction Notes	-
Material Properties and Potential Applications	Pemotex is a variant of Trevira flame-retardant textured filament Polyester yarns. It is a bi-component yarn with a low melt component that results in a stiffening of the textile surface at the finishing stage. Because Pemotex is flame-retardant potential applications include safety wear, textiles for interiors and product design. As the yarn reacts to heat treatment such as steam by shrinking and stiffening interesting textures and knit structures can be developed.

Appendix C

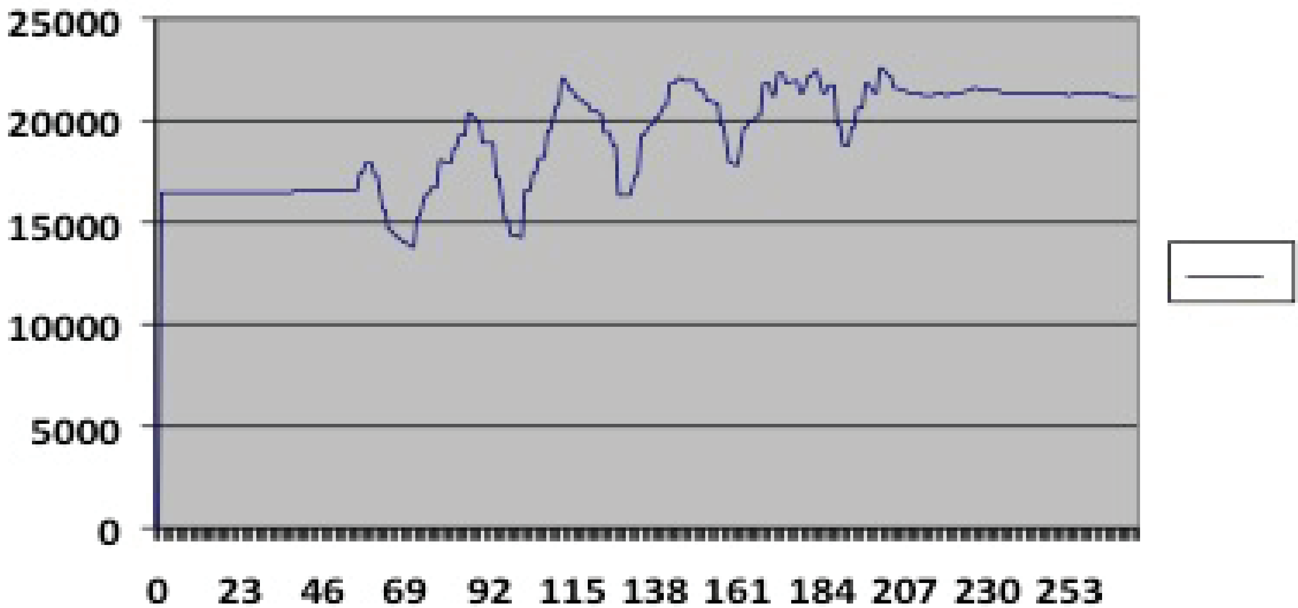
Material Testing

An investigation into conductive knitted jaquard structures. These conductive samples underwent testing to investigate the resistive capabilities of the composite structures. Each samples is a different combination of conductive and non conductive materials. This testing was carried out alongside Master of Engineering student Yasir Al-Hilali.

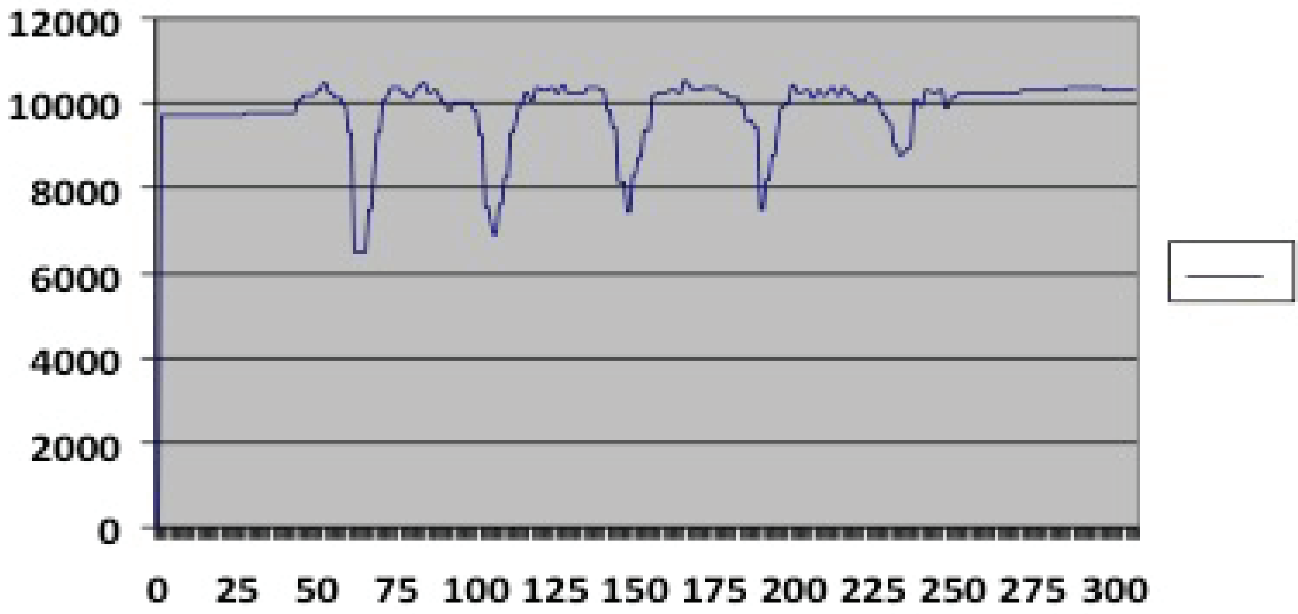
Sample One: Stainless steel / polyester yarn and merino tested for electrical response when 10 kg of force was applied.



Sample Two: Silk / Steel and Seacell yarn tested for electrical response when 10 kg of force was applied.



Sample Three: Silk / Steel and Bamboo yarn, tested for electrical response when 10 kg of force was applied.



Sample Four: Stainless steel / polyester yarn and merino tested for electrical response when 10 kg of force was applied.