

**STRONG  
WOOL  
SPEAKS**



# STRONG WOOL SPEAKS

Exploring a material  
conversation in the  
knitting of Strong Wool  
for acoustic design

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# ABSTRACT

Can the inherent properties and value of Strong Wool be amplified through a material-centric textile design practice?

Strong Wool is a highly technical, durable, biodegradable, and renewable natural fibre but its story is not being heard. Instead, the Strong Wool industry is overwhelmed by the noise of well-marketed plastic alternatives, poor understanding of its properties, and a lack of innovation in value-added manufacturing of the raw wool. This project proposes that listening to and responding to the fibre and its materiality allows for new conversations with Strong Wool and subsequently, the stories it can tell. The research adopts a material-centric approach alongside a digital knitting practice to explore acoustic textile outcomes.

In collaboration with Autex Acoustics, a proof-of-concept acoustic panel is developed within a framework that strives for a zero-waste production process and is dimensionally variable, commercially viable, and easy to install. This panel design is informed by a critique of how Strong Wool is understood currently and using tools, such as working across scales and visual storytelling, how it might be better understood is explored. The proof-of-concept artefact demonstrates how digital knitting augments Strong Wool properties. As a broader outcome, the research demonstrates how designing across scales with Strong Wool offers us tools to better design with the fibre. Specifically, it presents a sustainable design approach where we embrace the full breadth of the material through deeper conversations with it, with a focus on what Strong Wool is, and what stories it can tell.

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## 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.

23 May 2023

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## KEY TERMS

**Domestic hand-flat knitting machine:** These machines are designed for home craft machine knitting. Although electronic machines are available they are primarily analogue and manually operated.

**Fleece:** A single sheep's full covering of wool, usually shorn off a live sheep.

**Half gauge:** When every other needle of a machine is used to halve the effective gauge of a machine (i.e., a 14 gg machine when used at half gauge operates in effect as a 7 gg machine).

**Machine gauge:** Machines are given a gauge number (gg), which refers to the number of needles per inch on a machine's bed. A 5 gg has 5 needles per inch and creates a chunkier knit than a 14 gg, which has 14 needles per inch, is used for fine yarns, and creates finer fabrics.

**Strong Wool:** Also referred to as Coarse Wool or Carpet Wool, a fibre diameter of around 32 µm (microns) or more.<sup>1</sup>

**TEX count:** TEX is a linear density measurement for yarn, stating the weight in grams per 1000-metre length.

**Yarn plys or folds:** When a yarn is spun it is typically spun into a single strand known as a 'single.' When these singles are twisted together, in a process known as folding or plying, a stronger yarn is formed.

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<sup>1</sup> Economic Intelligence Unit, *Wool Data Book: Data to Support the Wool Working Group* (Wellington: Ministry for Primary Industries, 2019), 16, <https://www.mpi.govt.nz/dmsdocument/43201-Wool-Data-Book>.

# INTRODUCTION

Sheep were first introduced to New Zealand by Captain James Cook in 1773, and since the establishment of sheep farming in the mid-1800s their meat and wool has been a considerable component of this country's exports.<sup>2</sup> The majority of New Zealand's wool is the coarser Strong Wool<sup>3</sup> and, over time, its value and positioning as a fibre have changed. Currently, Strong Wool's voice is not being heard. The quality of the wool has not changed but the narratives and applications have.

## RESEARCH AIMS

As a designer researcher, my aim with this project is to amplify Strong Wool's voice through studio practice, prototyping and negotiating its path through commercial and industrial environments. More importantly, through reflective practice and storytelling, the research aims to provide a framework for extending the material's narrative as a high-performing, sustainable, and aesthetically appealing fibre.

Nature begins with the material; craft practice also begins with the material but contemporary design favours form. There is a magic to the heterogeneity of natural materials, and as designers we have so much more to work with when we engage with this uncertainty of difference (see fig. 1). By employing a material-based approach, this research looks specifically at digitally knitted Strong Wool, in an acoustic absorption context, with all its complexities and opportunities.

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2 Ministry for Culture and Heritage, "New Zealand's First Sheep Released 20 May 1773," NZ History, last modified January 20, 2021, <https://nzhistory.govt.nz/first-sheep-released-in-new-zealand>.

3 Te Kāhui Whaihanga NZIA, "Why Wool Is So Cool, and Why Wool Now?" March 10, 2021, webinar recording, <https://vimeo.com/522032879/2947165657>.

## RATIONALE FOR THE STUDY

If price were an indication of value, then Strong Wool is worthless, selling for less than the cost to shear the sheep.<sup>4</sup> It has not always been this way: in the 1950s, during the Korean War, Strong Wool farms enjoyed substantial returns.<sup>5</sup> One of the ways that the Ministry for Primary Industries' *Vision and Action for New Zealand's Wool Sector* report<sup>6</sup> responds to this issue is by advocating for research into consumer-focused innovation with Strong Wool that can be openly shared across the industry. The report points to a more environmentally and socially sustainable consumer providing new opportunities for this fibre.

With climate change, there is a strong imperative to respond by re-examining our approach to material resources. As designers, we have a huge role to play as the materials and processes we choose directly affect sustainability of humankind's production and consumption. A return to traditionally used biological materials would address issues of post-consumer waste. Materials such as Strong Wool, are biodegradable and reduce plastic pollution by offering an alternative to synthetic fibres. Alongside material choice, this research also considers how our design approach can be re-examined in order to accommodate biological materials more effectively.

## SCOPE AND ORGANISATION

The research follows a practice-based knitted textile design approach, where commercial aims are negotiated alongside academic design research aims.

This introduction is followed by a contextual review, methodology, critical and reflective commentary on practice, and finally a conclusion. The work culminates in an acoustic panel *conversation circle* (see fig. 67) alongside a wall of sample pieces. The exegesis follows a similar pattern and text is interlaced with sections of visual documentation of my textile practice.

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4 Gerhard Uys, "Wool Price So Low Farmer Says He's Losing \$5 per Sheep," Stuff, December 22, 2022, <https://www.stuff.co.nz/business/farming/agribusiness/130827927/wool-price-so-low-farmer-says-hes-losing-5-per-sheep>; Richard Gavigan, "Shearing Contractors Feel the Pinch," Country-Wide, April 1, 2022, <https://nz-farmlife.co.nz/shearing-contractors-feel-the-pinch/>; Neal Wallace, "\$1/kg Return a Nightmare for Wool Farmers," Farmers Weekly, January 27, 2023, <https://www.farmersweekly.co.nz/news/1-kg-return-a-nightmare-for-wool-farmers>.

5 Te Kāhui Whaihanga NZIA, "Why Wool Is so Cool."

6 Wool Industry Project Action Group, *Vision and Action for New Zealand's Wool Sector* (Wellington: Ministry for Primary Industries, July 2020), <https://www.mpi.govt.nz/dmsdocument/41079-Vision-and-action-for-New-Zealands-wool-sector-report>.



## POSITIONING STATEMENT

Part of the tune of my early years was the sound of sheep. On our 'lifestyle' block, my family had a small flock of sheep. When I was nine, my father built me a small loom and I worked exclusively in wool. Then, in my early teens, I learnt to knit and so began a lifelong delight in wool and its properties as a material.

I am a third generation (at least) engineer. Like my father and grandfather, I studied engineering, but unlike them, I felt at odds with the culture. Perception and behaviour were absent from my practice as an engineer, and the distance between what you designed and its construction seemed so vast. In 1996, I completed my civil engineering degree and pursued a different career, textile design. However, to say that I left behind my engineering when I graduated is false—on the contrary, I believe it has informed every element of my design practice.

I have noticed that I like to look for the logic of my textiles. To find the patterns, to quantify or qualify them while engaging more directly with materials and processes. I often observed that I approached my design practice from a distinctly engineering lens, when compared with my design contemporaries. While it was often this quality that won me jobs in the freelance world of costume textile design, it played a supporting role to my deeper interest in visual storytelling during the past twenty years working in the film industry. The meanings that motif, colour, pattern, and texture conveyed became my primary focus; techniques and execution followed.

In time, I have come to see that shifting perspectives between disciplines allowed me to see solutions and indeed find problems that I would otherwise miss. The researcher, professor, and designer Neri Oxman names this shifting of perspectives "antidisciplinary." Oxman proposes that if we constantly seek to change our views and perspectives, we enhance our potential intellectually. "Central (disciplinary) vision will get you far, but peripheral (antidisciplinary) vision will get you farther."<sup>7</sup>

**Facing Page:** Figure 1. Digitally knitted Strong Wool as a heterogenous pleated textile. Sarah Coxhead, *Heterogenous Pleating*, 2022.

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7 Neri Oxman, "Age of Entanglement," *Journal of Design and Science*, no. 1 (2016): 8, <https://doi.org/10.21428/7e0583ad>.

Oxman’s *Krebs Cycle of Creativity* graphic (fig. 2) provides a visual framework to explain how the creative disciplines of design, art, science, and engineering relate to and differ from each other. My practice exists primarily between the modalities of engineering and design, where utility is central but both knowledge and behaviour are important considerations.

Logic, engineering, textiles, craft, and storytelling are the instruments of this research. With this research, I use my unique positioning to amplify Strong Wool’s voice: a voice that is in dire need of hearing.

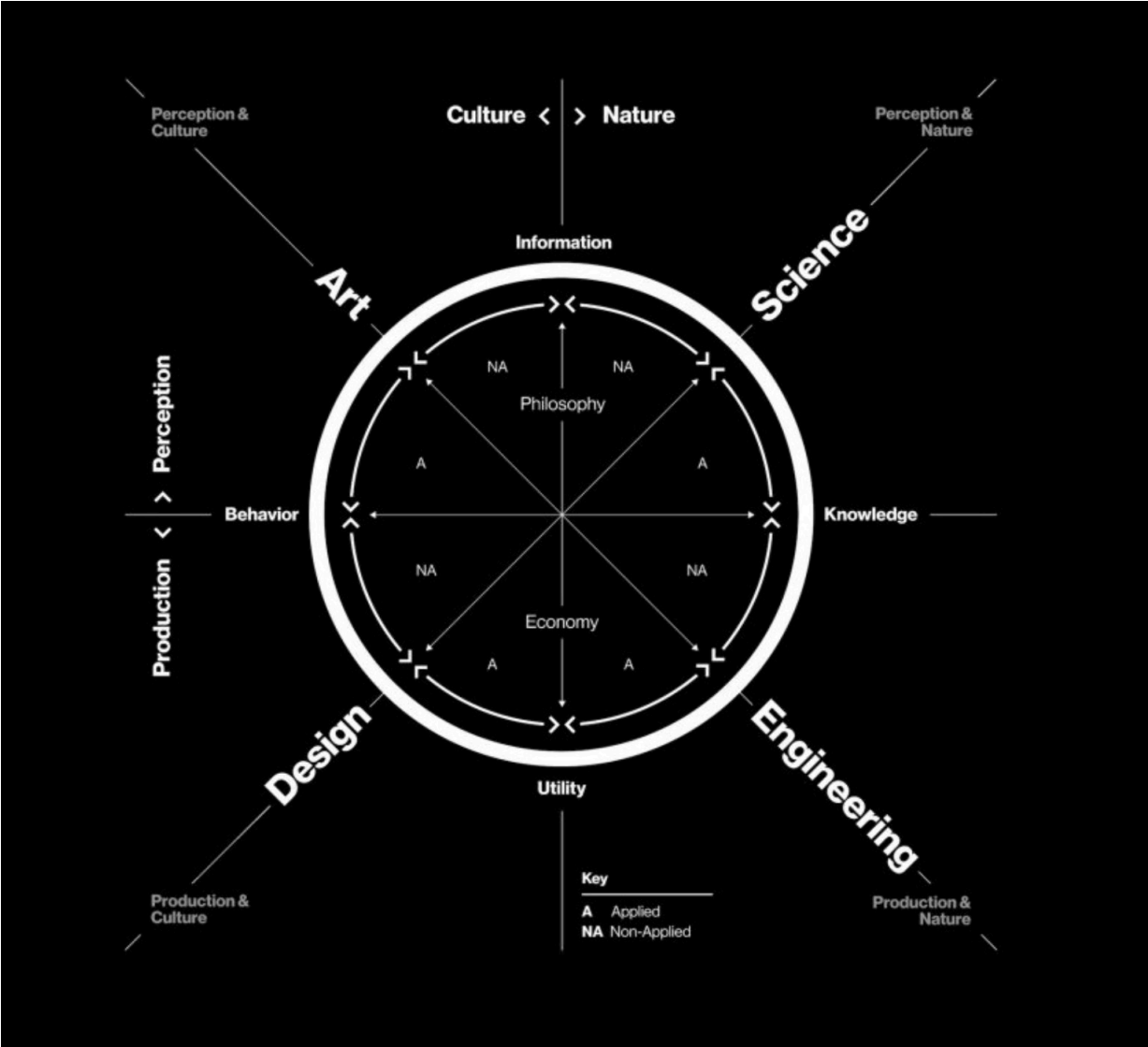


Figure 2. Movement between the disciplines, shown in the graphic, results in the generation of a creative energy. Neri Oxman, *Krebs Cycle of Creativity*, 2016. Reproduced from “Neri Oxman’s Krebs Cycle of Creativity,” *Spectrum*, Winter 2017, <https://spectrum.mit.edu/winter-2017/neri-oxmans-krebs-cycle-of-creativity/>.

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**This and facing pages:** Figures 3-6. Sarah Coxhead, *Tinkering with wool as paintbrush and inspiration for form*, 2022.



## CONTEXTUAL REVIEW

The central focus of this research is Strong Wool. Keeping an ear to the voice of the material is key. With a biological material such as Strong Wool, there is much to consider when scoping its potentials.

[Skilled practice] is a question not of imposing preconceived forms on inert matter but of intervening in the fields of force and currents of material wherein forms are generated. Practitioners, I contend, are wanderers, wayfarers, whose skill lies in their ability to find the grain of the world's becoming and to follow its course while bending it to their evolving purpose.<sup>8</sup>

The skilled practitioners that the anthropologist Tim Ingold refers to resemble more closely a craftsperson than a contemporary designer. When we craft, we are intimately engaged with the material.<sup>9</sup> Having a curiosity for the limits and potentials of the material is key in a craft practice. Oxman states that in contrast “with the exception of few pioneering cases in contemporary design, the secularization and debasement of the material realm has become axiomatic.”<sup>10</sup>

This leads to what Oxman describes as the “crisis of form,”<sup>11</sup> where form is considered first, and structure and material become form fillers. This in turn leads to poor use of resources, including material redundancy and waste. Oxman proposes that when we can deeply understand a material and how we can manipulate this material, there is the potential to emulate nature and allow material, along with functional and performance properties,

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8 Tim Ingold, *Being Alive: Essays on Movement, Knowledge and Description* (Milton Park: Taylor & Francis, 2021), 255, ProQuest Ebook Central.

9 Richard Sennett, *The Craftsman* (London: Penguin, 2008), 120.

10 Neri Oxman, “Material-Based Design Computation,” (PhD thesis, Massachusetts Institute of Technology, 2010), 27, <http://hdl.handle.net/1721.1/59192>.

11 *Ibid.*, 70.

to dictate form.<sup>12</sup> She uses the term Material Ecology to describe this approach. “Material Ecology is a pragmatic philosophy: a method of design and production that brings together humans, automated processes, and nature to transform architecture into a hybrid act of building and growing.”<sup>13</sup> Material Ecology provides some clues to effectively designing with biological materials; in particular Oxman’s approach of understanding the material across scales.<sup>14</sup>

## UNDERSTANDING MATERIAL ACROSS SCALES

In this research, Strong Wool is investigated across three scales of design influence:

1. **the micro scale**, where the fibre’s microscopic makeup is considered and an understanding for how it behaves and varies is gained;
2. **the macro scale**, which includes the factors that directly influence the properties of Strong Wool in a farming and production context;
3. **the systemic scale**, where more abstract influences are explored that can dramatically affect the way we as humans engage with Strong Wool.

This framework for exploring Strong Wool helps provide a more complete dialogue for the human–material interaction. It sets the scene for a conversation with Strong Wool in a knitted acoustic design practice, adding breadth and challenging the form-focused status quo.

### Strong Wool at the Micro Scale

Strong Wool (sometimes called Coarse Wool or Carpet Wool) is considered to have a fibre diameter of around 32  $\mu\text{m}$  (microns) or more.<sup>15</sup> The thickness of the fibre affects how easy it is to bend. At a greater diameter, fibres do not bend as easily, resulting in a prickly sensation when touched. As such, Strong Wool can be irritating to the skin, so is less suitable for apparel than finer-diameter fibres such as those found in Merino wool (10–25  $\mu\text{m}$ ). The scales on each fibre’s surface, known as cuticles (see fig. 7), allow it to attach easily to

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12 Oxman, “Material-Based Design Computation,” 74.

13 Paola Antonelli and Anna Burckhardt, *The Neri Oxman Material Ecology Catalogue* (New York: Museum of Modern Art, 2020), 9.

14 Antonelli and Burckhardt, *The Neri Oxman Material Ecology Catalogue*.

15 Economic Intelligence Unit, *Wool Data Book*, 16.

neighbouring fibres, making wool easy to felt or simply create air pockets between fibres. Both qualities are helpful for acoustic applications. The cuticles also increase the surface area of the fibre and provide a variable surface, which again aids acoustic properties. One of the smallest elements of the fibre is the helical coil, responsible for wool's flexibility, elasticity, and resilience, which are advantageous properties for the knitting process as well as for commercial product end use.<sup>16</sup>

Figure 7. Wool at the micro scale. Reproduced from University of Waikato, "Wool Fibre Structure and Properties," Science Learning Hub, accessed May 16, 2023, [https://www.sciencelearn.org.nz/image\\_maps/61-wool-fibre-structure-and-properties](https://www.sciencelearn.org.nz/image_maps/61-wool-fibre-structure-and-properties).



Figure 8. Early tinkering with raw wool revealed the heterogenous nature of the fibre. Sarah Coxhead, *Wool painting*, 2022.

**Facing Page:** Figure 9. Sarah Coxhead, *Wool painted*, 2022.

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16 University of Waikato, "Wool Fibre Structure and Properties," Science Learning Hub, accessed May 16, 2023, [https://www.sciencelearn.org.nz/image\\_maps/61-wool-fibre-structure-and-properties](https://www.sciencelearn.org.nz/image_maps/61-wool-fibre-structure-and-properties).



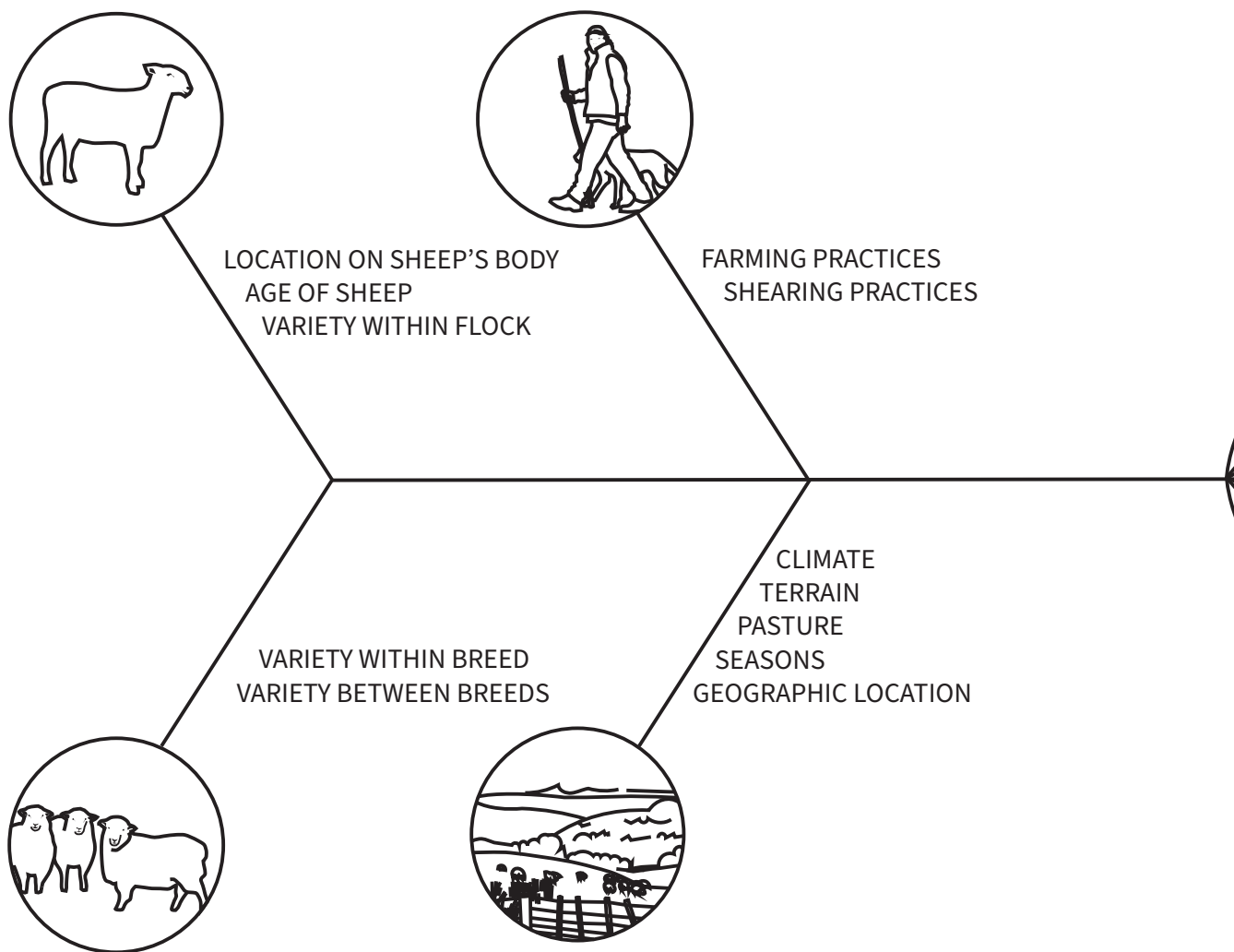
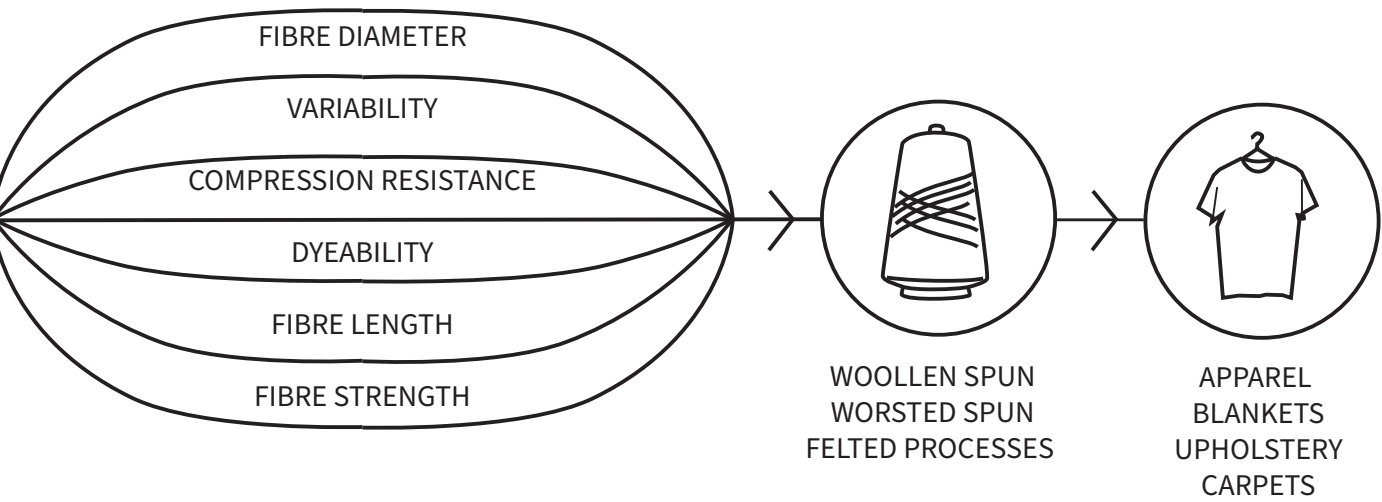


Figure 10. Sarah Coxhead, *The macro scale of wool production, and outputs*, 2022. Based on process described by Errol Wood, "Value and Use of Wool: Wool Marketing and Clip Preparation Lecture Notes," The Australian Wool Education Trust, 2017, <https://www.woolwise.com/wp-content/uploads/2017/07/WOOL-422-522-12-T-21.pdf>.



At the micro scale, there are many variables. Fibre diameter, variability within a fleece (see figs. 8 and 9), compression resistance of the fibre's structure, its readiness to take dye, the length of the fibre, as well as its strength, are just a handful of these. In the Strong Wool industry, these variables are usually manipulated by humans at the macro scale.

### Strong Wool at the Macro Scale

The macro scale (summarised in fig. 10) is composed of the influences on and practices of the wool industry, from breed selection, manipulation of farming practices, and monitoring of environmental influences, through to sorting or classing fibres to ensure efficient and economical matching of fibre properties to end-use requirements.

Oxman proposes utilising automation (or computation) across scales to efficiently structure material. In the case of the wool industry, the largely analogue methods of dealing with the complexity of a biological material do not scale well, and the demand for Strong Wool has dropped dramatically as industrial mass-production systems have taken hold and synthetic materials have neatly fit into the requirements of these systems. This trend took hold after the Second World War and was facilitated by more efficient industrial textile machinery, requiring a standardised raw material.<sup>17</sup> Strong Wool, with more natural variability than its Merino equivalent, was especially affected by this.<sup>18</sup> Once again, this speaks to what Oxman refers to as the *crisis of form* in modern design, where form precedes materialisation<sup>19</sup> and heterogenous materials are avoided rather than embraced.

*Aguahoja I* (see fig. 11) is a project developed by Oxman and the Mediated Matter Group at MIT. It provides us with a glimpse of ways we can use computational technologies as well as automation to build heterogeneously with biological materials. Using materials that can be obtained from natural origins, such as cellulose (from cotton fibre), chitin (crustacean shells), starch (corn), pectin (citrus fruits), and calcium carbonate (limestone), the team made solutions of varying concentrations. These solutions were then measured and compared by how they responded to environmental forces (structural, wind, radiation, light, hydration) (see fig. 12).

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17 W.S. Simpson, "Wool Production and Fibre Marketing," in *Wool: Science and Technology*, ed. W.S. Simpson and G.H. Crawshaw (Sawston: Woodhead, 2002), 1.

18 Simpson, "Wool Production and Fibre Marketing," 2.

19 Oxman, "Material-Based Design Computation," 27–30.

Figure 11. Neri Oxman and The Mediated Matter Group, *Aguahoja I*, 2014-2020. Reproduced from Oxman, "Project Aguahoja," accessed May 17, 2023, <https://oxman.com/projects/aguahoja>.

Figure 12. Multi-functional material combinations for *Aguahoja I* biopolymer pavilion. Reproduced from Oxman, "Project Aguahoja," accessed May 17, 2023, <https://oxman.com/projects/aguahoja>.

Data was collected on environmental forces acting across the surface of the proposed structure. Then a robotic arm deposited the solutions, to match the variable environmental requirements across the structure.

Perhaps it is through what Oxman refers to as this age of a *new materiality*<sup>20</sup> and more specifically recent technological developments, such as those in computational design, that heterogeneous materials such as Strong Wool can be better incorporated into the design and production process. In turn this would transform the perceived difficulties of designing with biological materials for commercial applications.

### **Strong Wool at the Systemic Scale**

The systemic scale includes material perceptions, as well as the factors affecting how we design and why we design. As the design researcher Joanna Boehnert suggests: “Typically, it [design] reproduces the values and priorities of those who determine which design problems are to be addressed.”<sup>21</sup> Acknowledging and signposting these influences is important. In this research, these influences include the New Zealand-based global acoustic company Autex Acoustics, and a government funding body, the Ministry of Primary Industries: Sustainable Food and Fibre Futures Fund. Economic, social, and ecological factors stemming from these influences have hugely impacted material selection, availability, and processing.

Autex Acoustics has a strong sustainability research and development agenda, featuring zero-waste, circular economy design, and sustainability more widely.<sup>22</sup> Digital knitting has a zero-waste potential, while offering digitally generated, repeatable designs that can be manufactured remotely. Strong Wool speaks to this sustainability agenda well, in not only providing circular economy recyclability but also being a renewable and biodegradable resource. These research and sustainability goals will be promoted within the methods.

Sustainability goals suffer when the context is too localised or centralised. So designing with the systemic scale clearly understood helps broaden the reach and environmental

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20 Oxman, “Material-Based Design Computation,” 28.

21 Joanna Boehnert, *Design, Ecology, Politics: Towards the Ecocene* (New York: Bloomsbury Academic, 2018), 4.

22 Autex Acoustics, “Autex: Our Sustainability Journey 2021,” accessed June 4, 2022, [https://www.autex-global.com/assets/Autex-Acoustics-Website/Landing-Pages/Sustainability/Foundation-Page/AG\\_EN-Our-Sustainability-Journey\\_Sept21\\_SB-4.pdf?vid=3](https://www.autex-global.com/assets/Autex-Acoustics-Website/Landing-Pages/Sustainability/Foundation-Page/AG_EN-Our-Sustainability-Journey_Sept21_SB-4.pdf?vid=3).

appropriateness<sup>23</sup> of our design solutions. As Boehnert explains, “Fragmentary thinking is an obstacle to sustainability.”<sup>24</sup>

Understanding how Strong Wool functions across our environment, economy, and society is essential to unlocking the drivers of the value attributed to it. Economically, Strong Wool has a low monetary value. Farmers are not covering the cost of shearing their sheep with the prices they receive for its sale.<sup>25</sup> This becomes a social issue, as it affects the economic sustainability of rural communities that are heavily reliant on the income from wool. As a result, farming practices change, wool quality and availability drops, and less money is available for the sheep farmer to protect biodiversity<sup>26</sup> or waterways.<sup>27</sup>

In my research, I have seen another reality to add to this: the low monetary value of Strong Wool is symptomatic of a lack of understanding for its properties and the apparent complexities associated with it. Within the social system, Strong Wool lacks a strong narrative,<sup>28</sup> so designers, manufacturers, and consumers do not know how to engage with it.

As a designer, I have been surprised how much of this research has involved advocating for Strong Wool. Manufacturers and commercially minded suppliers driven by profit and efficiency perceive Strong Wool as a poor fit for industrial mass-production systems. Where this culture exists, Strong Wool’s strengths are overlooked and rather than these strengths being built on, the fibre’s status declines, overtaken by homogenous synthetic fibres.

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23 Paul Hekkert and Matthijs van Dijk, *Vision in Design: A Guidebook for Innovators*, 330. Appropriateness: A final design is appropriate when it fulfils or adapts to the needs of the context it is designed for.

24 Boehnert, *Design, Ecology, Politics*, 98.

25 Gavigan, “Shearing Contractors Feel the Pinch”; Uys, “Wool Price So Low”; Wallace, “\$1/kg Return a Nightmare.”

26 Colin Williscroft, “Farmers Back Biodiversity Benefits,” *Farmers Weekly*, September 23, 2020, <https://www.farmersweekly.co.nz/news/farmers-back-biodiversity-benefits/>.

27 Neal Wallace, “Big Costs for Freshwater Compliance,” *Farmers Weekly*, October 2, 2020, <https://www.farmersweekly.co.nz/news/big-costs-for-freshwater-compliance/>.

28 Wool Industry Project Action Group, *Vision and Action*.

Further, consumers looking for sustainable materials are not being given a clear message in terms of Strong Wool's environmental impact.<sup>29</sup> As an example of confusion around the sustainability of sheep's wool, a Life Cycle Analysis (LCA) undertaken by the engineering researchers Jaehun Sim and Vittaldas Prabhu found that, in the United States, wool carpet compared unfavourably with nylon carpet with regard to energy consumption and carbon emissions.<sup>30</sup> While this study is a cradle-to-grave analysis, the environmental burden of wool was not correctly assessed, as human toxicity, eco toxicity and ecosystem impact were omitted.<sup>31</sup> Typically, LCA studies include water consumption, but fail to look at whether this resource is renewable or scarce in the locality; similarly, land use assessments do not consider whether this land is unable to be used for arable land or how carbon is sequestered in the soils.<sup>32</sup>

## CONVERSING WITH STRONG WOOL

The personification of Strong Wool in this research is used to focus attention on our relationship with the fibre, as well as to highlight the complexity and dynamics of this material. The anthropologists Mike Anusas and Tim Ingold summarise this material-centric design approach succinctly in the following statement:

In finding an alternative to the conventional logic of form, it should be possible to reimagine design as a practice that seeks to facilitate mediation and dialogue between people and their surroundings through enriched involvement with materials.<sup>33</sup>

Through an enriched connection with Strong Wool, I have become aware of our relationship to nature more generally. Making processes have evolved from material-led craft to form-led design, and our understanding for the natural systems of our world and the material

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29 Uys, "How Wool Has Come to Be Seen as Worse for the Environment than Synthetics."

30 Jaehun Sim and Vittaldas Prabhu, 'The Life Cycle Assessment of Energy and Carbon Emissions on Wool and Nylon Carpets in the United States,' *Journal of Cleaner Production* 170 (2018): 1242, <https://doi.org/10.1016/j.jclepro.2017.09.203>..

31 Caroline Devaux, "Wool Production: Systemic Review of Life Cycle Assessment Studies" (Degree project, KTH Royal Institute of Technology, 2019), 19.

32 *Ibid.*, 40.

33 Mike Anusas and Tim Ingold, "Designing Environmental Relations: From Opacity to Textility," *Design Issues* 29, no. 4 (Autumn 2013): 61.

opportunities that nature affords us has suffered. In response, the following chapters illustrate how a material conversation with Strong Wool underpins my practice, and demonstrates its benefits. By embracing the notion of craft and engaging fully with the fibre across the micro, macro, and systemic scales, we establish a fluency with the language of biological materials, enabling informed, sustainable design and making.



**This and facing pages:** Figures 13-16. Sarah Coxhead, *Explorations with domestic machine knitting crumple rib construction*, 2022..



# METHODOLOGY

## OVERVIEW

The biological heterogeneity of Strong Wool is a good metaphor for its associated material experience. A farmer who knows their flock's lineage, the seasonal changes, and the characteristics of their pastures will experience Strong Wool very differently from a designer who has always lived in a city and wants to use Strong Wool in designs for corporate clients. In making sense of my interaction with this material, an interpretivist theoretical perspective is beneficial. It allows me to think of the world not in singularities but dynamic multitudes; deepening the narratives and validity of diverse ways of seeing.

Within the interpretive theoretical framework, a Research through Design (RtD) methodological approach is used. Here, qualitative data is collected through the often messy process of making. Alex Taylor, a sociologist at Microsoft Research, discusses how RtD allows us to be open, helping to avoid compartmentalisation and purification of the conditions situating our research.<sup>34</sup> By looking for what could "be made interesting,"<sup>35</sup> discovered while journeying through design, RtD charts the continual growth that happens between the material and the maker.

One way of structuring this RtD process is a methodology known as Material Driven Design (MDD) developed by Elvin Karana et al. They argue that a material's widespread commercial success is dependent not just on the material's functional aptness but also the material experience it elicits from the user.<sup>36</sup> Karana et al. state that in order to understand the material experience, it is necessary to qualify a material based not only on *what it is* but also on the following perspectives:

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34 Alex S. Taylor, "What Lines, Rats, and Sheep Can Tell Us," *Design Issues* 33, no. 3 (2017), 33, [https://doi.org/10.1162/DESI\\_a\\_00449](https://doi.org/10.1162/DESI_a_00449).

35 *Ibid.*, 33.

36 Elvin Karana et al., "Material Driven Design (MDD): A Method to Design for Material Experiences," *International Journal of Design* 9, no. 2 (2015): 35.

- what the material does;
- what the material elicits from us;
- what the material makes us do.

The methodology is based on four key steps, illustrated in figure 17: understanding the material, creating a Materials Experience Vision, manifesting material experience patterns, and finally creating material or product concepts.<sup>37</sup>

Figure 17. Material Driven Design (MDD) process map. Reproduced from Elvin Karana et al., "Material Driven Design (MDD): A Method to Design for Material Experiences," *International Journal of Design* 9, no. 2 (2015): 40.

Using this methodology, I found my research was not one of these four-step cycles but three, as shown in the following map of my thesis process (see fig. 18). I have further qualified the processes by labelling them as predominantly *listening* or *storytelling*. Listening constitutes a reflective process where Strong Wool is being heard through direct interaction, contextual research or critical review. Storytelling takes the form of vision and object making based on conceptual or physical interpretations of these listening processes.

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37 Karana et al., "Material Driven Design," 39–40.

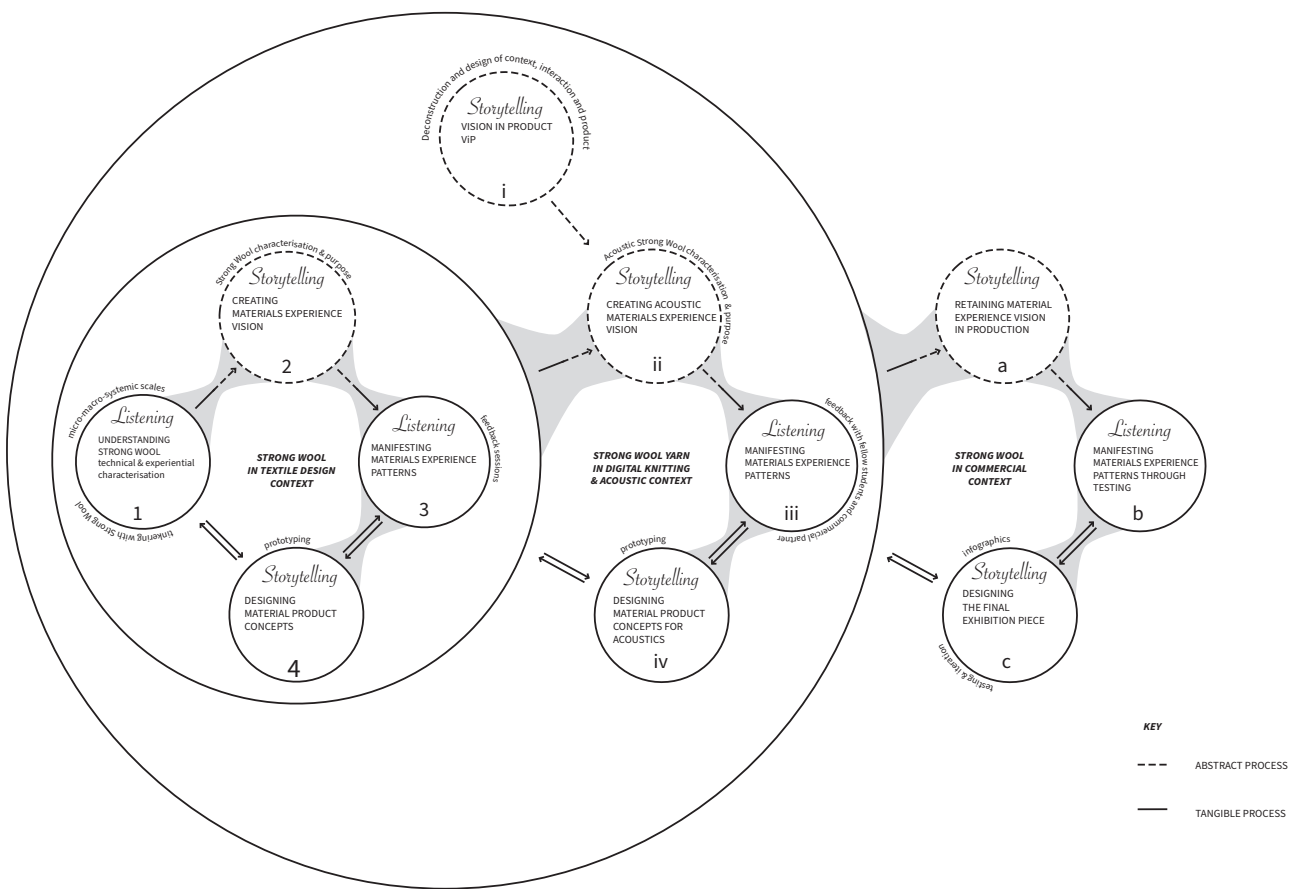


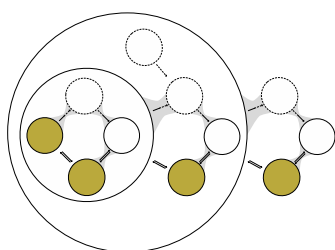
Figure 18. Sarah Coxhead, *Map of my thesis process*, 2023.

## METHODS

The key methods used in this research were iterative sampling, digital design, critical review, and narrative. These are briefly introduced here, and further discussion and application of these methods in practice are documented in the following chapter.

### Iterative Sampling

If we look to the thesis process map (see fig. 18), this sampling method dominated the highlighted sections:

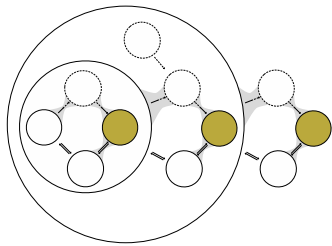


Sampling is a predominantly tangible process involving visual storytelling with the material—but constant listening is also key. This is how craft works: the material and craftspeople are involved in a dialogue. The sampling process includes digital knitting, acoustic design thinking, tinkering with yarn and raw Strong Wool.

### Digital Design Methods

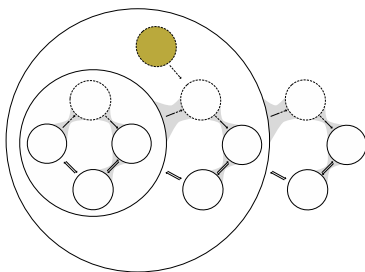
Within the iterative sampling process, digital design tools are used to execute, understand and communicate. These tools are the Shima Seiki digital knitting software (Apex), Adobe Illustrator, Procreate iPad drawing app, Rhino 3D modelling software and its associated computational design software Grasshopper. These are used to test ideas, assist communication and automate processes, so predominantly are used in storytelling.

## Critical Review



The Review and Feedback steps primarily involve listening. The listening here is not directly with the material, as in the sampling process, but with the external responses to the material, forms or vision. It is a testing ground for the practice: ensuring my material conversation is being told in a way that speaks to its intended audiences, and beyond my individual practice. Strong Wool's systemic scale is especially apparent here. These sessions took the form of acoustic testing, informal conversations, discussions with industry, brainstorming and personal reflection on practice.

## Vision in Product (ViP)



ViP evaluates existing products in the design domain by deconstructing their designed attributes, interaction qualities, and past contexts (see fig. 19). This reflection provides a starting point for a construction of an imagined context, interaction, and product design.<sup>38</sup>

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38 Paul Hekkert and Matthijs van Dijk, *Vision in Design: A Guidebook for Innovators* (Amsterdam: BIS, 2011).

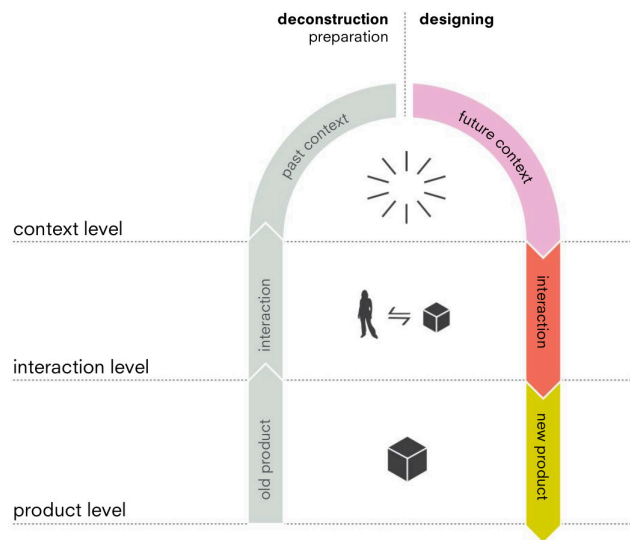
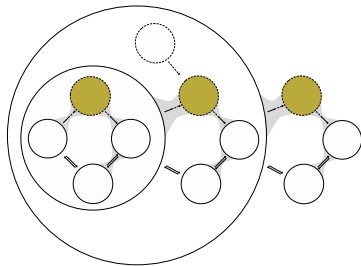


Figure 19. Three levels of description in the ViP model. Reproduced from Paul Hekkert and Matthijs van Dijk, *Vision in Design: A Guidebook for Innovators* (Amsterdam: BIS, 2011), 133.

## Narrative



In the MDD structure, this process is referred to as *creating the Materials Experience Vision*. In my practice, this is specifically creating a Strong Wool narrative; that is, using conceptual thinking to imagine Strong Wool as a key voice in the interaction between object and audience.



**This and facing pages:** Figures 20-23. Origami trials using digital knitting inlay machine where float yarns are inserted digitally into the knitting, these float yarns are then pulled to create form. Sarah Coxhead, *Digital knitting origami using an inlay machine*, 2022.



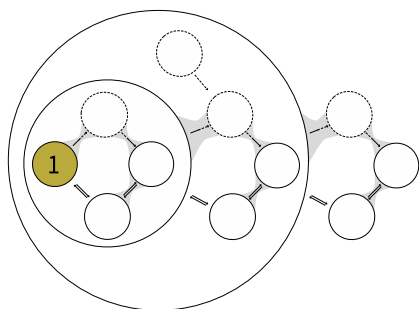
## CRITICAL AND REFLECTIVE COMMENTARY ON PRACTICE

This section provides a critical and reflective commentary, demonstrating how the contextual framing and methods referenced in the previous chapters are applied in practice. The commentary is not linear in time. Instead, the thesis process map provides the structure and broadly indicates the flow of the practice. At times, it was necessary to return to a step, to review or refine.

Key reflections addressed in the following commentary are:

- When moving from a more general Strong Wool textile design to a more focused acoustic textile design process, the Materials Experience Vision had to be adjusted from one where a natural, technical quality was sought, to a nurturing, peaceful material experience.
- In tinkering with Strong Wool in my textile practice, specifically on the digital knitting machines, the importance of being able to connect with the fibre at the micro and macro scale was revealed.
- Retaining the Materials Experience Vision in a commercial context was often difficult and on reflection would have been helped with the use of visual mood boards and swatch books.
- The openness of practice was crucial. Seeing failures as opportunities for learning rather than prompts to look elsewhere was key. The choice of MDD as a methodology supported this openness.

## UNDERSTANDING STRONG WOOL



In this research, Strong Wool is understood *or listened to* through three key explorations. I began by tinkering<sup>39</sup> with the raw material before use of digital knitting as a method, where I explored “how it can be shaped/embodied in products.”<sup>40</sup> These earlier phases then informed a technical and experiential characterisation phase,<sup>41</sup> where Strong Wool’s story is reflected on more broadly.

### Tinkering with the Raw Material

Tinkering<sup>42</sup> is where the material experience begins. What is Strong Wool saying and what role can I play in telling its story? I carry with me a lifetime of living with wool, which is embedded in this interaction, but what can I learn anew? I began with a visit to a farm in the Kaipara district, north of Auckland (see fig. 24). The farmer, new to farming, had fleece lying around and was unsure what to do with it.

I had no idea of this wool’s micron count or technical specifications. It was raw wool. All my senses heard its story, I noticed the way each fibres of the fleece clung together, like a discarded cape, fibres interlocking, the lanolin scent rising from it; the length of the locks (known as staples) longer in some areas, shorter in others; the variability of colour across the fleece and within the fibres. It was an undulating landscape of texture, colour and depth.

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39 Karana et al., “Material Driven Design,” 41–42.

40 Ibid., 41.

41 Ibid., 41–42.

42 Ibid.



Figure 24. Sarah Coxhead, *Arapawa sheep on the Kaipara farm*, 2022.

The wool's springiness reminded me of a sponge and I wondered how it might work as a mark-making tool. With just my hand and the black ink as talking partners, the wool told its story of contrasts between simplicity and complexity. Each fibre, with its unique narrative, contributed to the whole voice (see fig. 25).

Progressing this mark-making further into form-making, I used the marks as starting points for exploring form, using a crumple origami technique demonstrated in the origami artist Paul Jackson's book *Folding Techniques for Designers: From Sheet to Form*<sup>43</sup> (see fig. 26).

**Facing Page:** Figure 25. Sarah Coxhead, *Raw Strong Wool as paintbrush*, 2022. Ink on paper.

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43 Paul Jackson, *Folding Techniques for Designers: From Sheet to Form* (London: Laurence King, 2011).





Figure 26. Sarah Coxhead, *Crumple origami translation of Strong Wool painted marks*, 2022.

I was intrigued by the organic nature of the crumple origami and used my domestic hand-flat knitting machine to translate this crumpled texture into knitted Strong Wool stitch architectures (see fig. 27).

I used missed needles in a rib set-up to create an uneven pleated structure. I then documented a cross-section of the resulting form against a knit notation template (see fig. 28). This was in turn translated into Rhino and Grasshopper.

Rhino and Grasshopper were new tools to me and I wanted to explore their use in form finding. In this case, they proved useful as a representation of the knitted swatch, but the digitisation smoothed the planes of the form and the natural heterogeneity of the wool was lost (see fig. 29).

**Facing page:** Figure 27. Sarah Coxhead, *Domestic hand-flat knitting machine translation of crumple origami*, 2022.



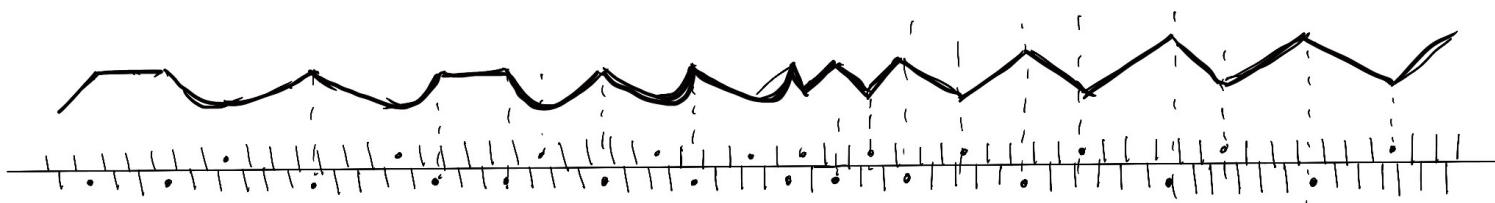


Figure 28. Sarah Coxhead, *Cross-section of crumple knit form alongside knit notation and domestic hand-flat machine set-up, 28  $\mu$ m wool yarn, 2022.*

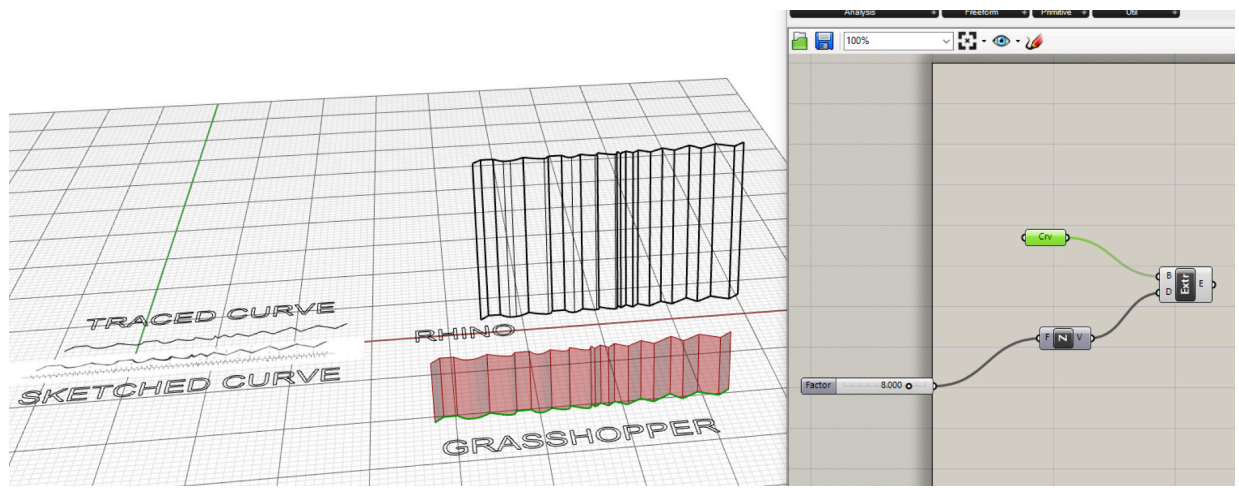


Figure 29. Sarah Coxhead, *Rhino and Grasshopper software used to translate the crumple knit cross-section into a textured surface*, 2022.



Figure 30. Sarah Coxhead, *Digital knitting translation of the crumple origami using wool*, 2022.

By contrast, the translation of the crumple origami through automation on the digital knitting machine retained the gentle heterogenous texture of the fibre in the form (see fig. 30). It becomes a nod to Oxman's Material Ecology, where automation is used as an efficient way of imitating and working with nature as a heterogenous material.

This crumple origami exercise was exciting at the time, in that it prompted me to find ways of expressing heterogeneous form for digitally knitted Strong Wool. However, as I embraced traditional forms of paper origami as a medium to explore form in parallel to knitting, I lost sight of this material-based approach. Both the concept of heterogeneity, and the material qualities of Strong Wool as a yarn, were lost in the outcomes.

As the paper form in figure 31 and its translated knitted form in figure 32 show, the latter relied on compression and failed to tell the story of Strong Wool's strengths. This was a key learning point in the practice and a useful example of the perils of form-led design.

### **Strong Wool in a Digital Knitting Context**

Knit designers typically work with yarn rather than the raw fibre. Strong Wool yarns can be fragile and bulky relative to more widely understood wools such as Merino, which have a lower micron count, and are typically spun with the stronger worsted spinning process. A key phrase from *Knitting Technology: A Comprehensive Handbook and Practical Guide* by David Spencer resonated with this research. Spencer notes, "knitting requires a relatively fine, smooth, strong yarn with good elastic recovery properties."<sup>44</sup> While Strong Wool has good elastic recovery properties as a fibre, it is typically spun using a woollen spinning process. This produces a relatively thick, uneven, and weak yarn, so there are conflicts in using Strong Wool in a commercial digital knitting context. Working with this challenge was a key aspect of my practice. This is where I see the dual approaches of craft, with its material consciousness, and storytelling, with its social consciousness, playing an important role.

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44 David J. Spencer, *Knitting Technology: A Comprehensive Handbook and Practical Guide*, 3rd ed. (Ston: Woodhead, 2001), 4.

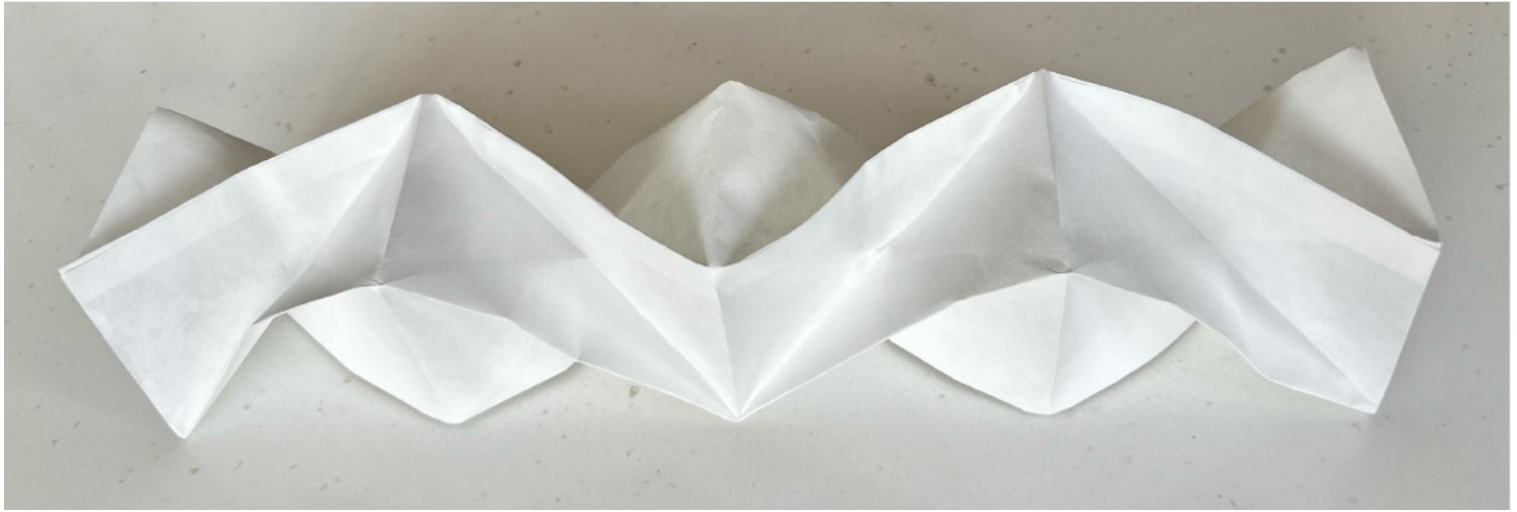


Figure 31. Sarah Coxhead, *Continuous box spirals*, 2022. An adaption of stacked box spiral forms by Paul Jackson, *Folding Techniques for Designers: From Sheet to Form* (London: Laurence King, 2011), 88.



Figure 32. Sarah Coxhead, *Translated box spiral form in digitally knitted Strong Wool*, 2022.



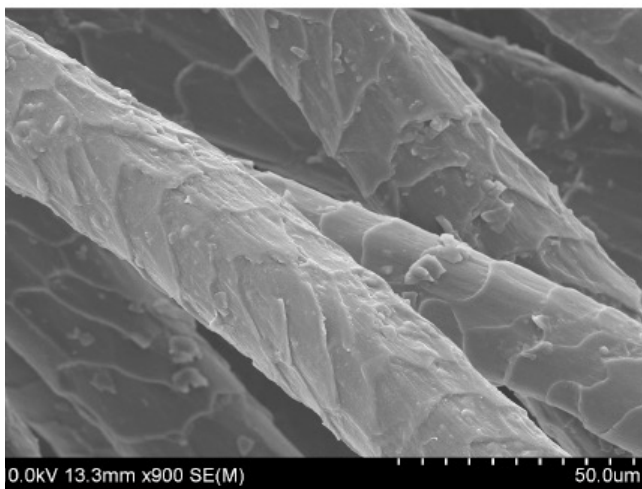
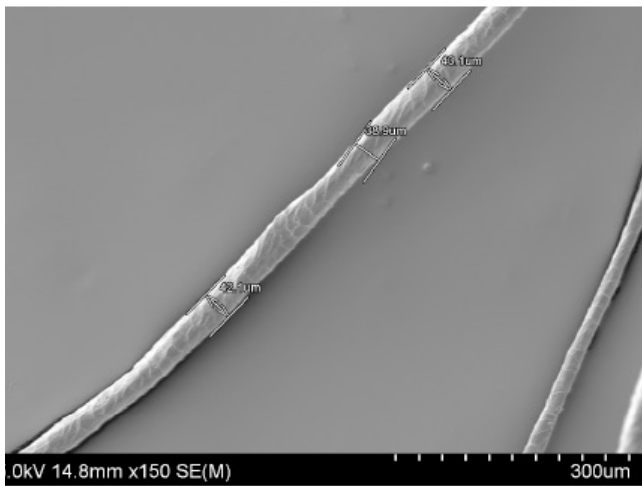
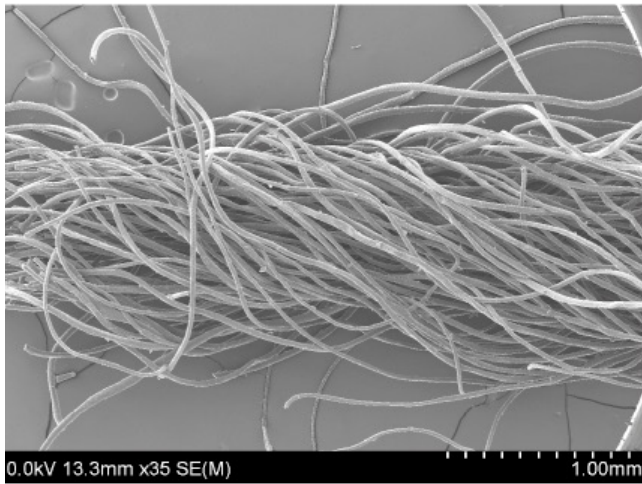
Figure 33. Sarah Coxhead, *Early Strong Wool sample where yarn breakages were common*, 2022.

The initial transition from my domestic knitting machine to the digital knitting machine was fraught. Early samples contained many holes from yarn breakage (see fig. 33).

Initially, a few boxes of old wool yarns (see appendix A) were used for sampling. With sparse yarn specifications available for these, it became difficult to understand the factors at play when one yarn failed and another succeeded. This research primarily relied on the visual assessment of the dead stock yarns. From this, rough guidelines for working with Strong Wool in a digital knitting context were made (see appendixes B and C). However, it was apparent that the missing link was data about the origin and production of these yarns.

Subsequently, I worked with a spinning mill specialising in carpet yarn, and I was given micron count and the details on spin (woollen spun), but I knew little of the blend of wool qualities used. It worked well on a 5 gg machine, but not on an 8 gg machine. Again, there was a separation from the farm, meaning I lacked the information to improve the yarn's knittability.

### Worsted Strong Wool Yarn



### Woollen Strong Wool Yarn

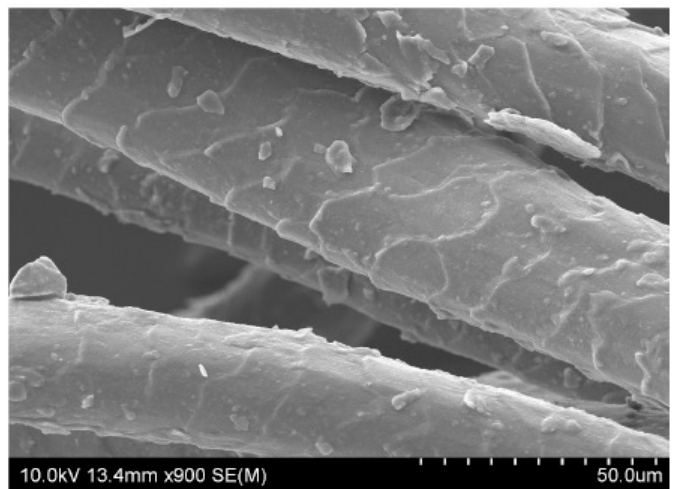
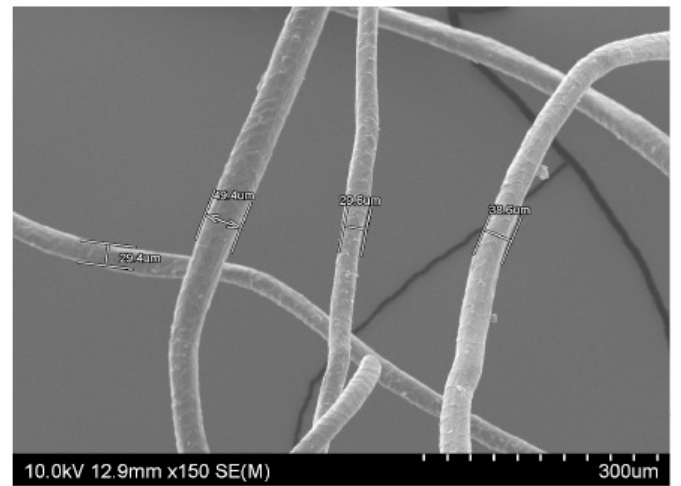
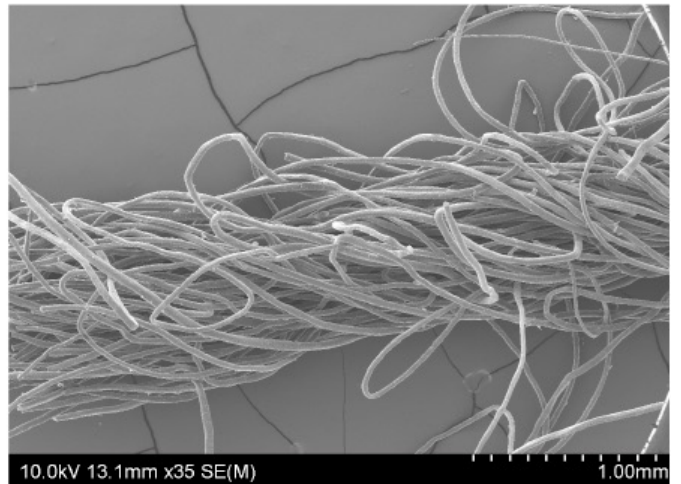


Figure 34. Scanning electron microscope (SEM) images comparing the worsted-spun with the woollen-spun Strong Wool yarn. Produced by AUT SEM Lab, 2023.

I was also given some yarn developed by a farmers' cooperative, for knitting apparel on 7 gg circular knitting machines. This yarn was spun using the worsted spinning system. As part of a cooperative that sells garments made from their fibre, the farmers are incentivised to ensure the quality of the fleeces matches the needs of the processing, and get direct feedback from the spinners, knitters, and customers. The resulting yarn uses long 34  $\mu\text{m}$  and larger fibres and is smooth, strong, lustrous, and knits well.

Figure 34 shows a sample of each yarn observed under a scanning electron microscope. The observable differences in the two yarns were the amount of twist (the worsted having more twist, as seen in the more upright angle of the fibres across the yarn), more uniform arrangement of fibres in the worsted yarn, and slightly less definition in the cuticle cells (see fig. 7) of the woollen-spun fibre. While I am not able to make definitive assessments on why the worsted is a better knitting yarn, the differences in these images reinforce the need for a connection with the micro scale when working with Strong Wool.

The bigger lesson in all of this was that yarn knittability is a careful balancing act between machine settings and yarn qualities. Unexpectedly, the difficulties in communicating aspects of this balancing act to my research partners revealed a need for better representation of this knowledge. In response, I developed infographics that became a feature of a later step in the thesis process.

### **Strong Wool Technical and Experiential Characterisation Review and Reflection**

An important step in the MDD process is the technical and experiential characterisation of the material, which is an articulation of a material's unique offerings in product development.<sup>45</sup> My tinkering with both the raw wool and yarn in a digital knitting context are key elements of this characterisation. Given that Strong Wool is a fully developed material, there is also the potential to use information outside of my direct interaction.

According to Stewart Collie of AgResearch, the four main technical characteristics of Strong Wool in an architectural context are:<sup>46</sup>

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45 Karana et al., "Material Driven Design," 41–42.

46 Te Kāhui Whaihanga NZIA, "Why Wool Is So Cool."

**Interaction with Moisture:** Comfort levels in interior environments can be improved with wool. Its capacity to absorb water vapour from humans and their activities lowers humidity and makes a room more comfortable for its inhabitants.

**Absorption of Volatiles:** Examples of volatiles are formaldehydes, sulphurs, and odour-causing gases. Wool has a higher capacity than other fibre types to absorb these, improving air quality by passively filtering out harmful volatiles.

**Flammability:** It is inherently non-flammable, so for furniture products it requires no fire-retardant chemical treatment.

**Biodegradability:** Synthetic fibres break down slowly into smaller particles known as microplastics. By contrast, wool degrades to its basic elements, which can easily be absorbed back into the environment: it is even being used as a fertiliser.

In addition, Strong Wool is an incredibly resilient fibre and naturally stain-resistant, and has equivalent or higher sound absorption properties than mineral wool or recycled polyurethane foams.<sup>47</sup>

Further technical characterisation emerged from use in the digital knitting machines. Here it was established that Strong Wool as a knitting yarn tends to have relatively poor strength, high linear density, and high variability.

Experiential characterisation, as addressed by Karana et al. in their MDD method, is explored across four experiential levels: sensorial, interpretive (meanings), affective (emotions), and performative (actions and performances).<sup>48</sup> Alongside widely understood characteristics, it is my direct experience of working with Strong Wool that informs a considerable component of this experiential characterisation:

**Sensorial:** Strong Wool is typically scratchy on the skin and it can have a strong scent of lanolin.

**Interpretive:** In New Zealand, wool is part of our cultural heritage, revered for providing wealth in the past and creating durable products. This reverence is contrasted with the notion that it is old fashioned, much like knitting, associated with smelly wet school jumpers. There is a new societal interpretation forming, however, and the recent report

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47 Romina del Rey et al., "Characterization of Sheep Wool as a Sustainable Material for Acoustic Applications," *Materials* 10, no. 11 (2017): 1277, <https://doi.org/10.3390/ma10111277>.

48 Karana et al., "Material Driven Design," 41–42.

*Vision and Action for New Zealand's Wool Sector*<sup>49</sup> suggested we are “on the cusp of a natural fibre renaissance led by more environmentally and socially conscious consumers.”<sup>50</sup>

**Affective:** Wool as protection, warmth, and comfort is due in part to the technical characteristics of the fibre but also related to its traditional use in baby clothes, carpets, and activewear.

**Performative:** Wool promotes touch. Its soft haze reassures visually, and the gentle slub of its yarn makes it approachable. The immediate warmth it provides also promotes direct interaction. Strong Wool's typical prickliness, however, is a disadvantage. What Strong Wool loses in softness it gains in durability when compared to finer/softer wools.

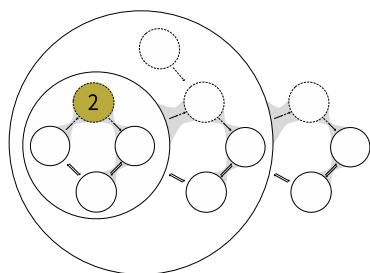
These characterisations supported the next step of creating a Strong Wool Materials Experience Vision, ensuring the design process was informed by the qualities of the material.

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49 Wool Industry Project Action Group, *Vision and Action*.

50 *Ibid.*, 5.

## CREATING A STRONG WOOL MATERIALS EXPERIENCE VISION



Understanding what my design process is trying to achieve is key. What is the role that I am hoping Strong Wool will play as a textile in the world? It starts with knowing what it is capable of, and what is intrinsic to the material. It is further extended by how I can amplify these properties through design, and in this phase of the thesis process map, through textile design specifically.

My textile practice has many facets, but for this research I am focusing on the knitted textile. In Oxman's Material Ecology, automation is embraced as a tool to bring us closer to ecologically effective design. This intrigues me and I can see there is an opportunity to explore this through digitally knitted Strong Wool. As each stitch is programmable, there is enormous potential for refinement and modification. But in this phase of the cycle, the question is: to what end?

What I learned while researching Strong Wool is that its technical characteristics are impressive. It compares well with its synthetic counterparts, but its expression in textiles is often poorly defined and lacking refinement. When felted or tufted, it does not speak loudly as a technical textile. Digital knitting provides us with a solution to this.

In response, the initial textile-based Materials Experience Vision (MEV)<sup>51</sup> for my research was:

The Strong Wool textile will express its natural technical superiority through a technically refined expression in textiles, allowing people to immediately understand the value of this fibre. A fibre that is biodegradable, renewable, and sustainable, while at the same time able to clean the air in our environments, absorb sound, moderate moisture, and be inherently strong and resilient.

Figure 35 shows Miro boards (an online whiteboard tool) of early exploring natural technical textiles with hyperlinks and images.

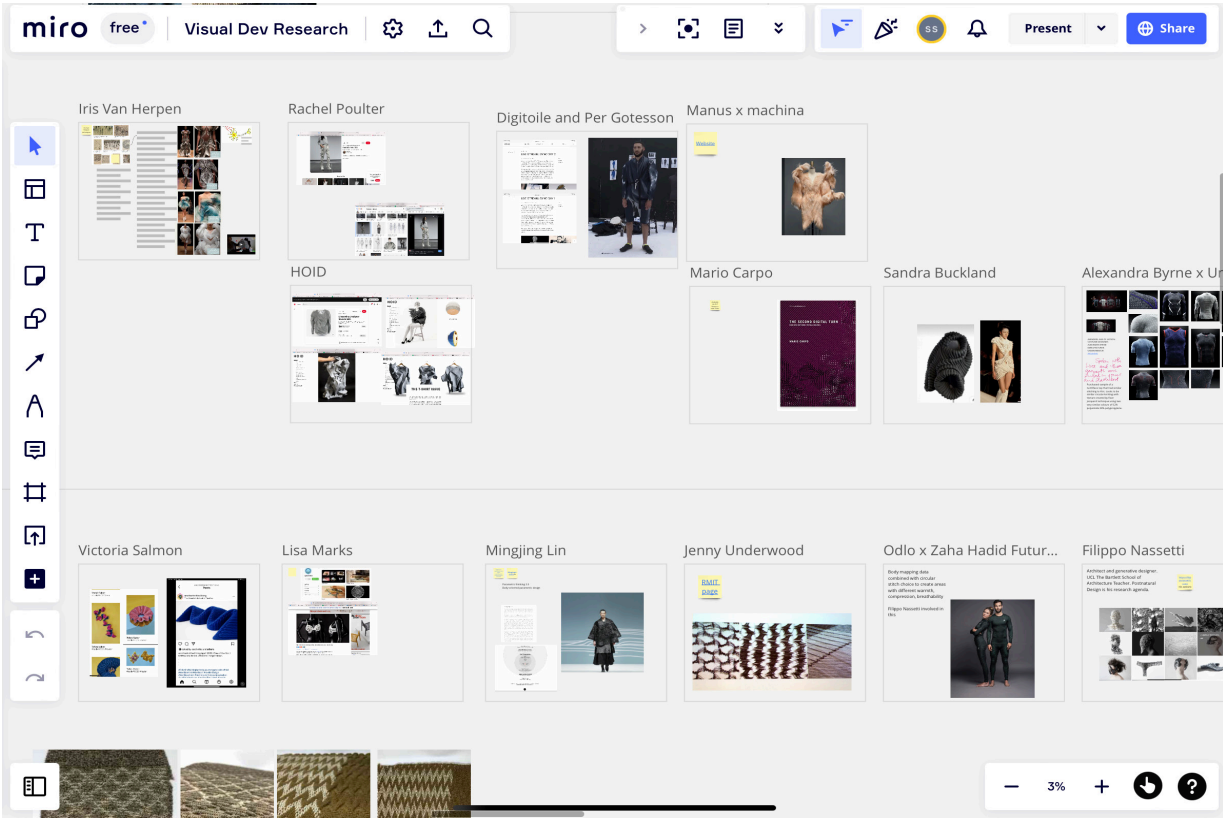
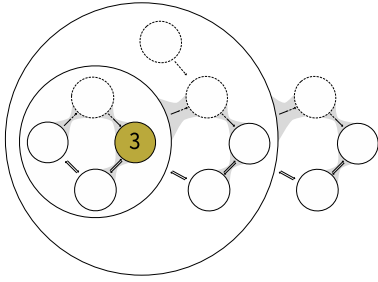


Figure 35. Sarah Coxhead, Section of an early inspiration board, using the online whiteboard software Miro, 2022.

51 Karana et al., "Material Driven Design."

## MANIFESTING MATERIALS EXPERIENCE PATTERNS FOR STRONG WOOL



Materials Experience Patterns in MDD are the prompts that elicit the desired MEV response. Manifesting the desired qualities of the material experience was progressed through exploration of two key attributes: natural and technical. Many contemporary designers are exploring these two attributes in a field known as computational design. Although there is a common aesthetic to computational design, it is not a style, per se. Rather, it is the embracing of the computational power of computers to build a form instead of imposing a form. Zaha Hadid Architects experiments with computational design, primarily in architecture, but also in other design disciplines. Examples of the firm's work with digital knitting are its KnitCandela project and Zaha Hadid Design's Futureskin collection with Odlo. Futureskin uses stitch and yarn qualities variably across the surface of the fabric to match areas of the garment where warmth or breathability need to be maximised to respond to the wearer's body (see fig. 36).

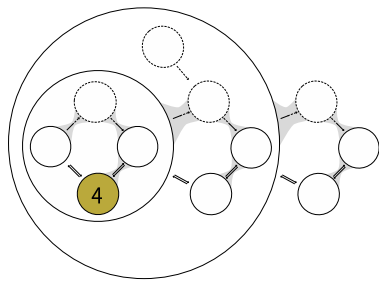
The resulting garment is futuristic but there is a naturalism to the distribution of the pattern, much like a zebra's stripes respond to the curve of its body.

Figure 36. Digitally knitted Futureskin variable yarn and stitch garments by Zaha Hadid Design and Odlo, 2018. Reproduced from "Odlo Futureskin Base Layer Collaboration with Zaha Hadid Design," Zaha Hadid Architects, January 30, 2018, <https://www.zaha-hadid.com/2018/01/30/the-odlo-futureskin-base-layer-collaboration-with-zaha-hadid-design/>.

Figure 37. A digitally knitted polyester formwork in tension created the foundation of this concrete shell structure by Zaha Hadid Architects, 2018-2019. Reproduced from "KnitCandela," Zaha Hadid Architects, accessed May 17, 2023, <https://www.zaha-hadid.com/design/knitcandela/>. Photograph by Juan Pablo Allegre.

Equally, the form of the *KnitCandela* (see fig. 37), where the knit is used to provide complex curves, is more reminiscent of a naturally formed shell than a human-formed archway. Taking this thinking forward into my textile prototyping, I was interested in variability and complex curves to provide a naturally technological visual.

## DESIGNING MATERIAL PRODUCT CONCEPTS: Textile Design Visual Storytelling



Creating stitch textures or architectures provided me with a vehicle for expressing the Materials Experience Vision. This approach was used to create a variable surface, an undulation that would look simultaneously complex and simple, much like nature.



Figure 38. Digitally knitted origami inspired forms using cotton and thermoplastic yarns to create form by Victoria Salmon. Reproduced from Victoria Salmon, "Dynamic Folding Knits: Play // Interact // Explore" (master's thesis, University of Borås, 2020), 69, <https://www.diva-portal.org/smash/get/diva2:1455073/FULLTEXT01.pdf>.

Inspired by Victoria Salmon's work where she explored origami forms with digitally knitted synthetic and natural yarns (see fig. 38), I experimented with thicker folds. Initially the exploration was in regular folds and utilised Merino wool (see fig. 39).

The Merino wool performed well on the knitting machine: it is fine, smooth, strong, and has good elasticity. Moving to Strong Wool, revealed how much more difficult it was to create a quality textile with this material. After many iterations, a pleated surface free from flaws was created (see fig. 40).

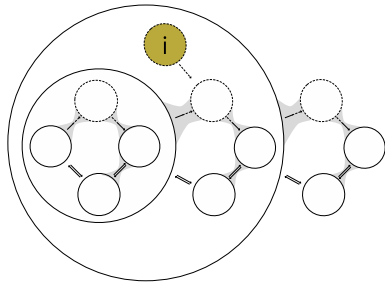


**Above:** Figure 39. Sarah Coxhead, *Early exploration with digital knitting origami with Merino wool*, 2022.

**Facing page:** Figure 40. Sarah Coxhead, *Digital knitting origami with Strong Wool*, 2022.



## VISION IN PRODUCT: Deconstructing Acoustic Products



Nestled within the second step of creating a Materials Experience Vision is a method developed by Paul Hekkert and Matthijs van Dijk, known as Vision in Product Design (ViP).<sup>52</sup> In early discussions with Autex Acoustics, I was given examples of products that they felt could inspire the process. These examples proved useful as deconstruction pieces for the ViP method.

Deconstruction prompted reflection on the success of existing products within the domain (acoustic absorbers). This helped to understand what material experiences are valued and expected in this domain, and also what contextual factors may have been considered in the design process (see fig. 41).

Existing product deconstruction helped me to better understand the future world that my product might exist in. A list of imagined contextual factors for approximately two years' time were listed and clustered, as shown in figure 42.

The next step in the ViP process is to create a Design Response Statement.<sup>53</sup> By identifying larger themes that can accommodate the contextual factors, a statement of how I intended to respond as a designer was developed (see fig. 43).

**Facing page:** Figure 41. ViP deconstruction of existing products summarised to show key reflections. Sarah Coxhead, *Deconstruction of existing products within the acoustic absorber domain*, 2022.

52 Hekkert and van Dijk, *Vision in Design*.

53 *Ibid.*, 102–4.

# CHARACTER

customisable  
natural  
elegant  
clarity  
modern  
tactile  
designed  
solid  
inviting  
unique  
an artwork  
desert sand dunes  
controlled organic  
visually dynamic  
sound diffusion  
repurposed waste

# INTERACTION

Inviting yet  
somewhat aloof  
  
Contemplation  
  
Meditation  
  
Curation  
  
Values signaling  
  
Congruent with  
modern aesthetic  
  
Relax and work

## existing product deconstruction

# CONTEXT

Natural product refined and made beautiful - nature and elegance aligned  
Allows for individual curation of the tiles - express creativity & uniqueness  
Busier environments require peace and quiet to balance them  
People are looking to declutter their lives  
Absorption is a silencer, a bringer of peace and serenity in a manic world  
An opportunity to reconnect with oneself and something elemental  
People want choice about how they work

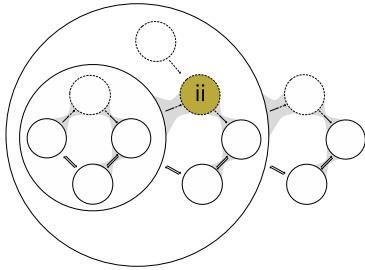


Figure 42. Sarah Coxhead, *Imagined contextual factors in two years' time, when product is ready for market, 2022.*



Figure 43. Sarah Coxhead, *Identification of larger themes (pink boxes) from imagined contextual factors with a Design Response Statement, 2022.*

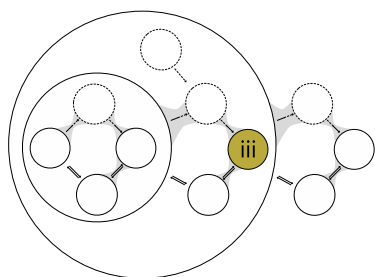
## CREATING AN ACOUSTIC STRONG WOOL MATERIALS EXPERIENCE VISION



The earlier textiles Materials Experience Vision is challenged by the ViP Design Response Statement. Rather than try to impress with sophisticated technology that in some way harnesses nature's own strengths, the focus is now on a nurturing and peaceful material experience.

The acoustic Strong Wool materials experience vision is an evolution from the initial materials experience vision: I want people to feel at peace with the material, have a familiarity and tactile connection with it; like a wise old friend that they are meeting again, someone who listened and always made everything seem OK.

## MANIFESTING EXPERIENCE PATTERNS FOR ACOUSTIC STRONG WOOL



Perhaps the strongest manifestation of nurturing in textiles is seen in natural curves and soft, fuzzy surfaces. Wool easily achieves a fuzzy halo finish and easily lends itself to the notion of nurturing, as discussed earlier.

Critiquing my textile samples for this nurturing quality came simultaneously with the realisation that I wasn't actually listening to the material, and had become very form-led. The design process started with paper origami forms but, when translated as knitted pieces, the form's depth and texture was lost unless a synthetic fibre was added or it was held in permanent compression (see fig. 44 and 45).

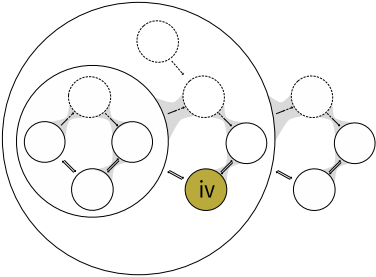
In response, I returned to listening more closely to the material rather than imposing forms upon it. This shifted my thinking to the creation of forms in tension, drawing from the properties of Strong Wool as a resilient yarn that can be stretched within a knitted textile. As seen in the final exhibition piece, complex curves can be created through the natural behaviour of the material in tension.

**Facing page, top:** Figure 44. Strong Wool knit pleated structures, such as this one, are only tentatively held in their form. Their inclination is to return to a flat, unfolded form (see fig. 45). Sarah Coxhead, *Temporary folds*, 2022.

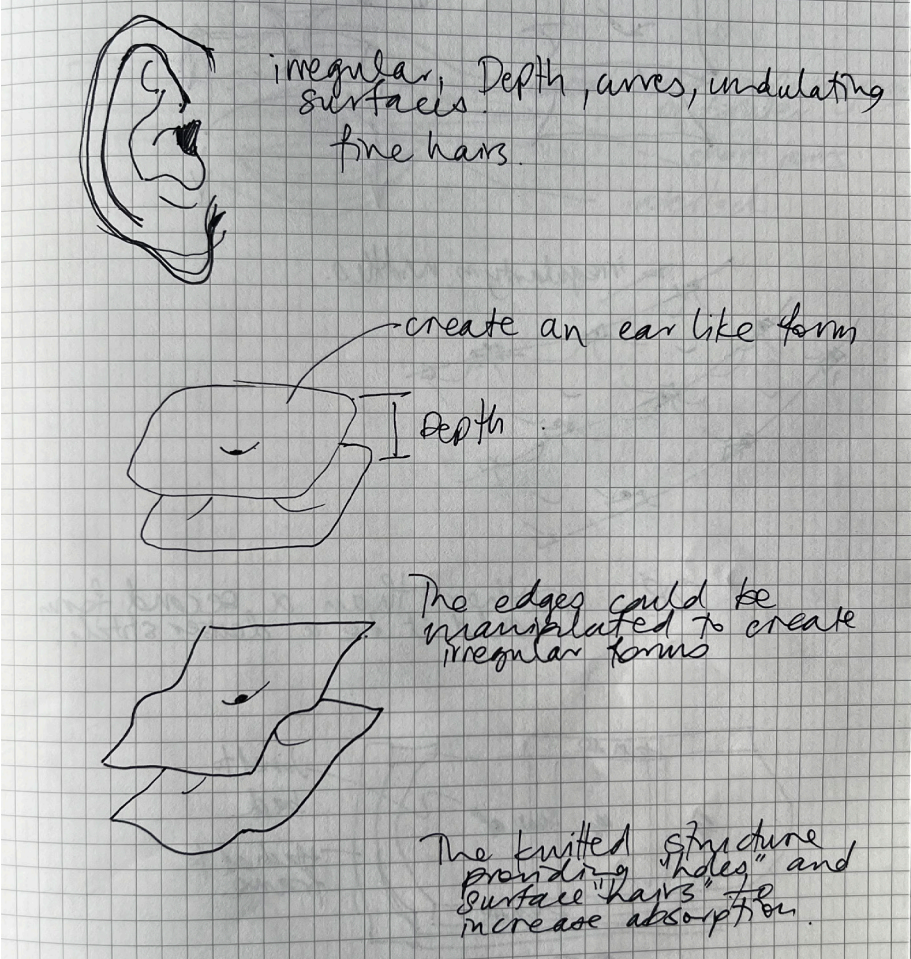
**Facing page, bottom:** Figure 45. Sarah Coxhead, *Unfolded folds*, 2022.



DESIGNING MATERIAL PRODUCT CONCEPTS: Acoustics Visual Storytelling

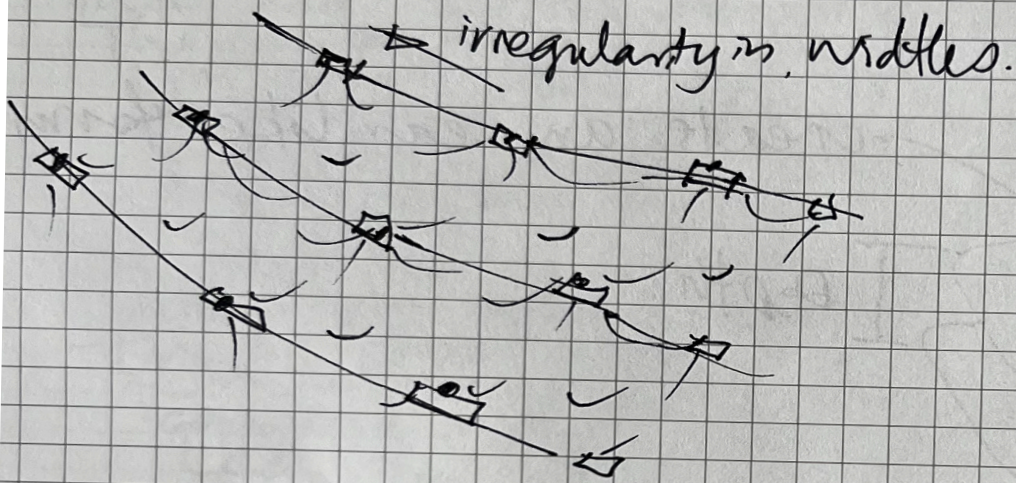
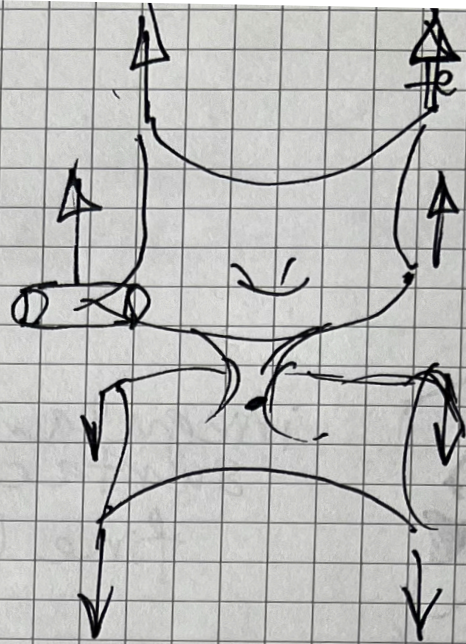
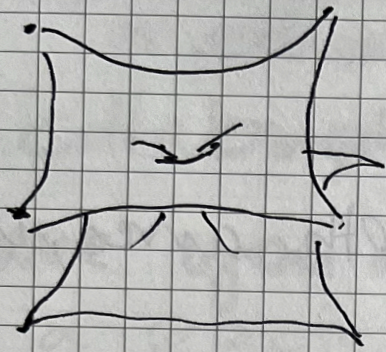


Thinking of “a wise old friend who listens” provided me with a visual prompt of an ear. Through sketchbook notes and drawings (see figs. 46 and 47), I was able to arrive at a material concept that was sympathetic to the digitally knitted Strong Wool’s capabilities.

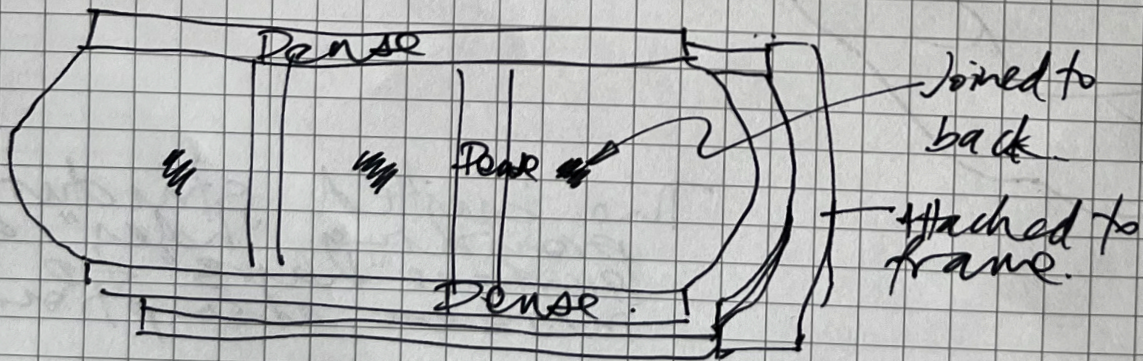


**This page:** Figure 46. Sarah Coxhead, *Sketchbook notes, exploring the development of a knitted form from the visual prompt of an ear, 2022.*

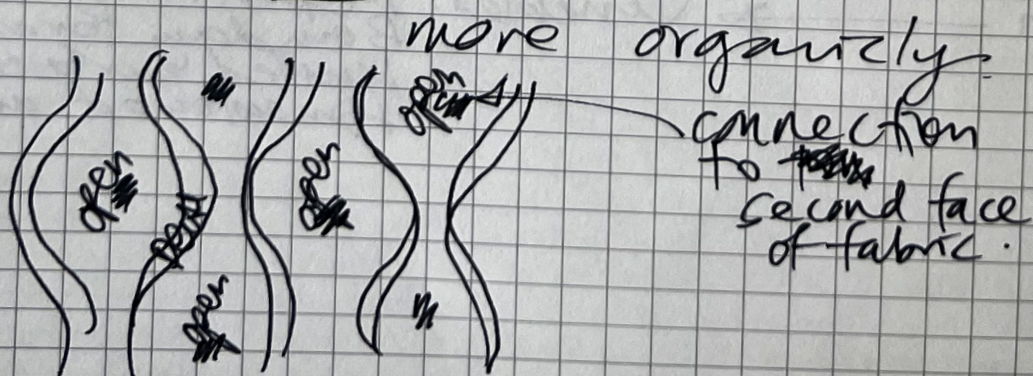
**Facing page:** Figure 47. Sarah Coxhead, *Sketchbook notes exploring tension concepts, 2022.*



OR rather than a second form could it be a denser stitch.

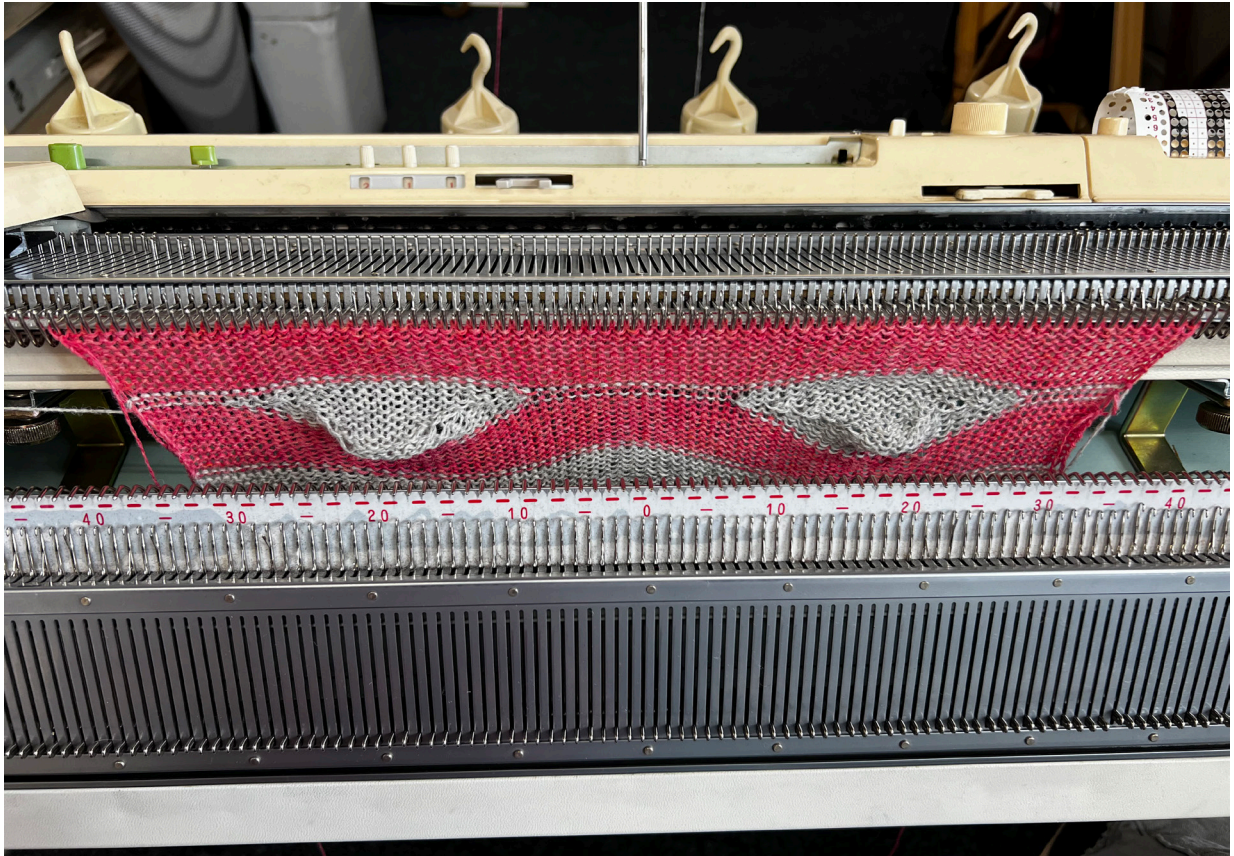


OR









**Previous spread, left:** Figure 48. Internal view of funnels where separate surfaces knit on domestic knitting machine have been handstitched together at base of funnels. Sarah Coxhead, *First funnel prototype internal view*, 2022.

**Previous spread, right:** Figure 49. Domestic knitting machine funnel prototype, colour changes used to highlight how rows of stitches are formed. Sarah Coxhead, *First funnel prototype elevation view*, 2022.

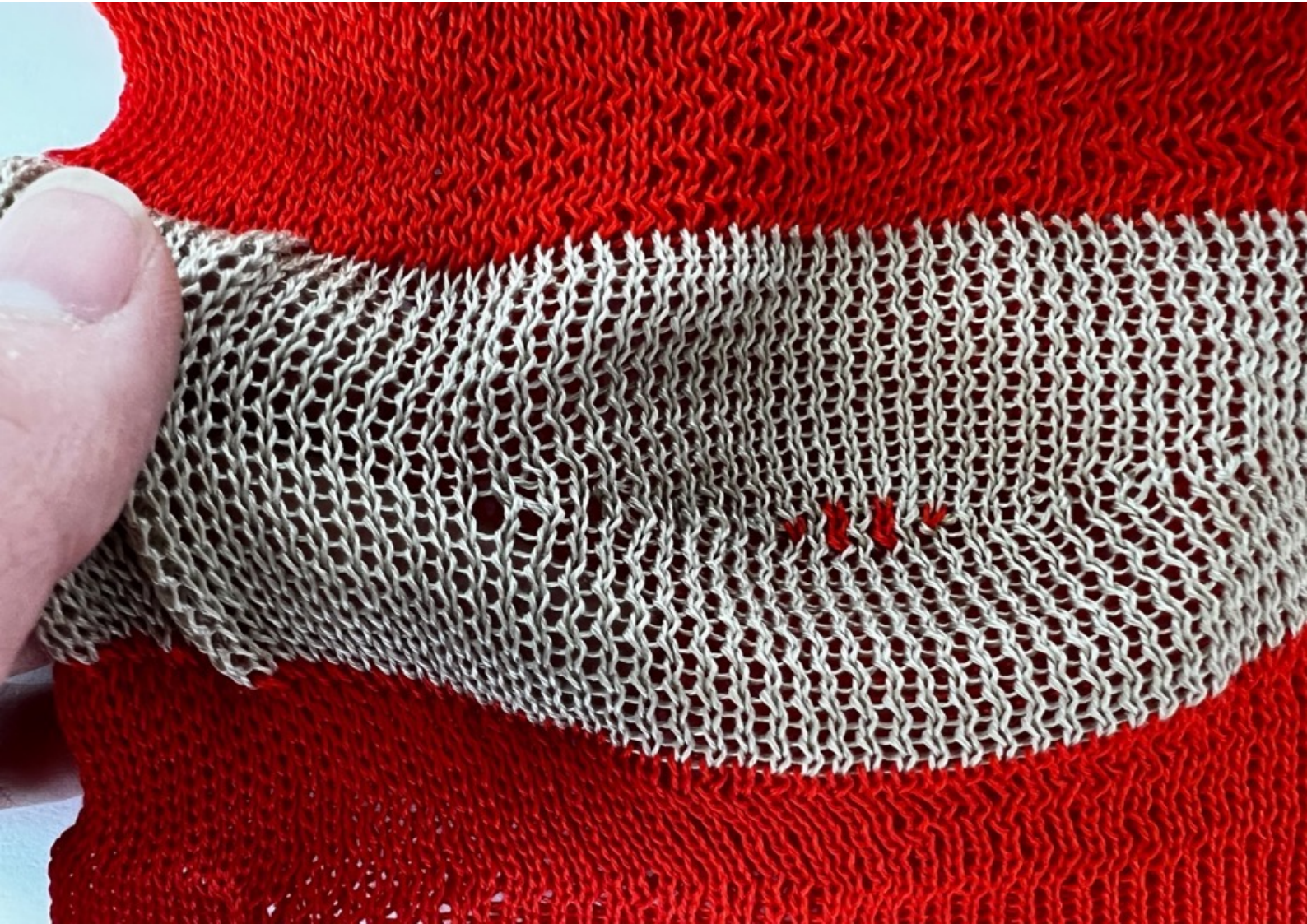
**Above:** Figure 50. A single surface of the funnel form being knit on a domestic knitting machine. Sarah Coxhead, *First funnel prototype in construction*, 2022.

**Facing page top:** Figure 51. Digital knitting machine sample with open sides and join between faces only. Sarah Coxhead, *Digitally constructed funnel trials 1*, 2022.

**Facing page bottom:** Figure 52. Funnel short-row stitches included. Sarah Coxhead, *Digitally constructed funnel trials 2*, 2022.

I translated the 'ear' funnel concept on my domestic knitting machine, as an analogue testing space, before translating it to the digital knitting environment (see figs. 48–52).

What excited me about this new material concept was the complex curves it could create with the simplest of constructions. The wonder was returned to the material and the way it naturally responded in tension.



I constructed small frames for a number of samples to illustrate the concept in Strong Wool (see figs. 54 and 55).

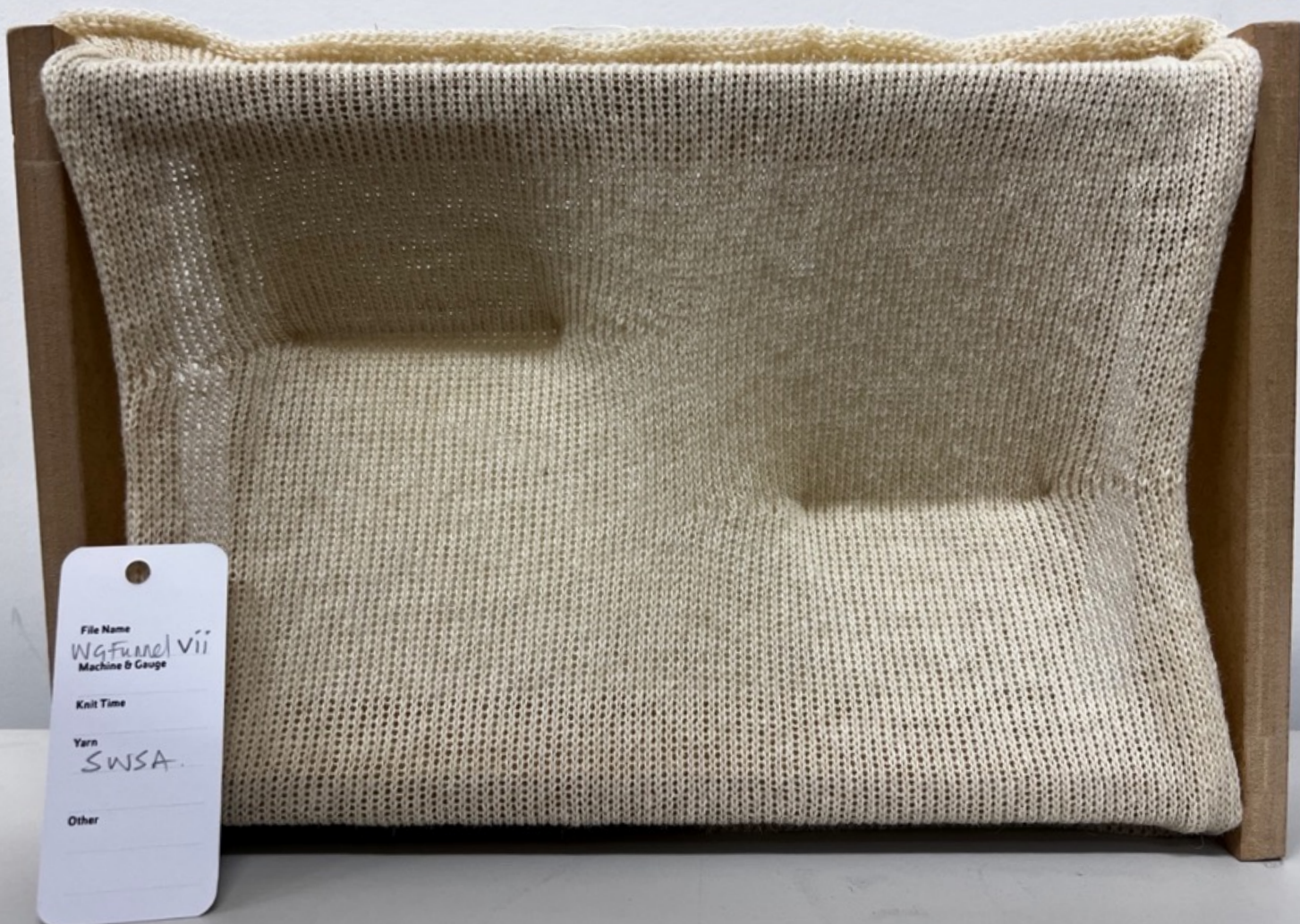
These samples were reviewed by Autex Acoustics and together we used a brainstorming session to consider possible acoustic products (see fig. 53).



**Above:** Figure 53. Our sketches from the acoustic product brainstorming session at Autex Acoustics. Sarah Coxhead and Jonathan Mountfort, *Commercial product brainstorming sketches*, 2022.

**Facing page top:** Figure 54. Recreation of hand-flat funnel concept using digitally knitted Strong Wool. Sarah Coxhead, *Strong Wool funnel panel trial 1*, 2022.

**Facing page bottom:** Figure 55. Funnels constructed with an elongated base join. Sarah Coxhead, *Strong Wool funnel panel trial 2*, 2022.



Three product ideas were proposed:

- 1) A panel with a single offset join detail
- 2) A circular frame with a single offset join detail
- 3) A cube frame where the funnel join is revealed

The frames were to be prototyped by Autex Acoustics, while I led the development of the textile elements. Behaviour and construction of the knit and how the product would be created, transported, and erected was discussed over multiple meetings. It was realised that in order to have a seamless appearance to the rectangular panel, the faces of the knit would have to be joined perpendicular to my original samples and the funnel shape would have to be dropped. This turned out to be a fortuitous move, as the new panel-knit 'sock' construction was a happy marriage of simplicity and complex curves, an expression of nurturing form (see fig. 56).

The circular frame proved too complex as a knitted form. This would push the Strong Wool's to the limits of its tensile strength and the resulting piece would likely reflect the construction complexity. This would be in conflict with the nurturing Material Experience Vision.

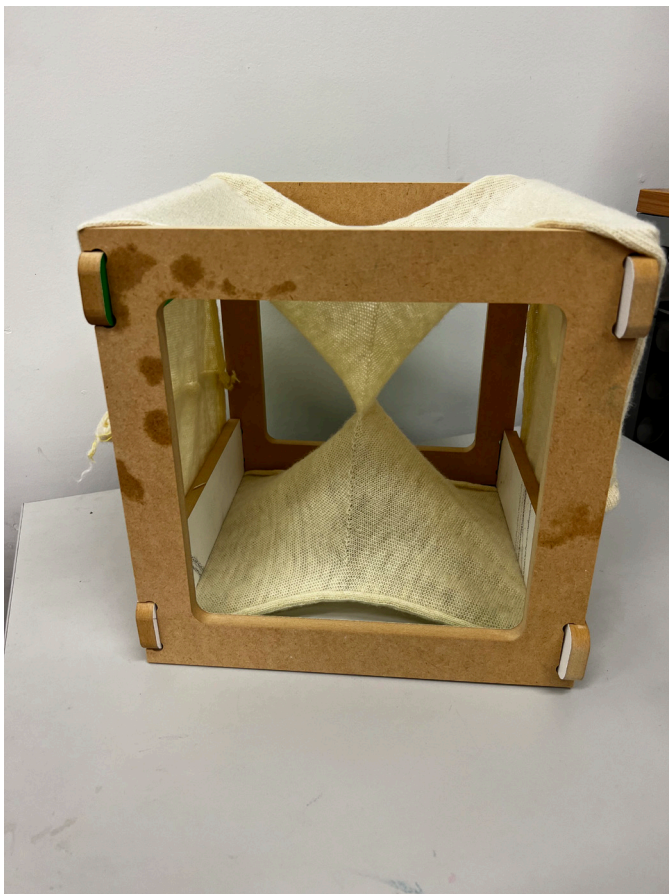
The cube frame worked well in the early prototypes (see figs. 57 and 58). But the concept as a whole was more playful than peaceful (see fig. 59), especially when compared to the panel shape (see fig. 56). My initial colourways were too full of energy also and Autex Acoustics used their colour consultant, Imogen Tunnicliffe to suggest a palette, which I then refined down to twelve colours (see fig. 60). These had a natural New Zealand sensibility. The colour half kelp in particular resonated with me as a shade of green that is typical of New Zealand's native flora. This colour has been used throughout the thesis.

**Facing page:** Figure 56. Knitted 'sock' covering uses a 34+  $\mu\text{m}$  woollen-spun Strong Wool yarn, 3 x 140 TEX, knit on a 5 gg machine. Sarah Coxhead, *First full-scale prototype*, 2023.





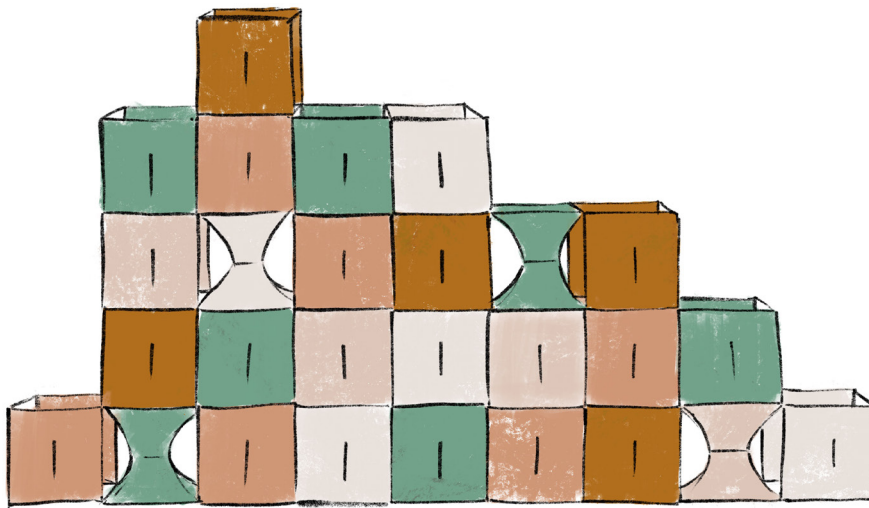
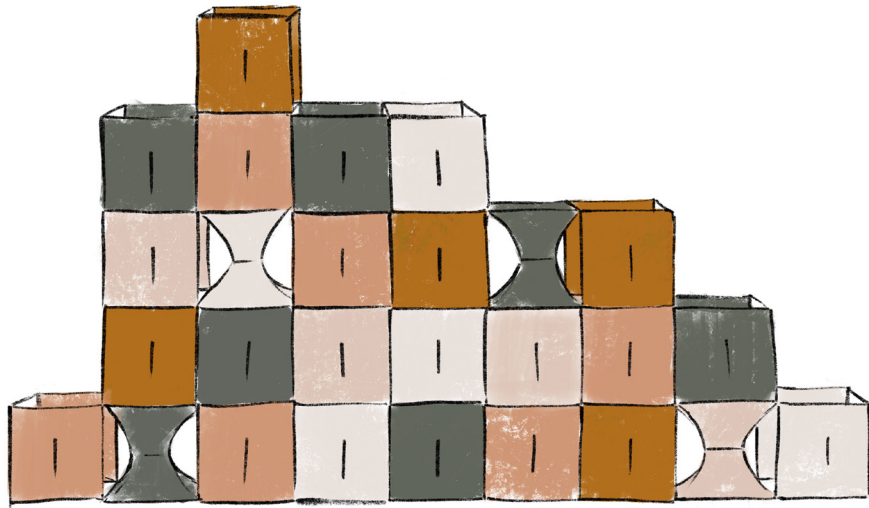
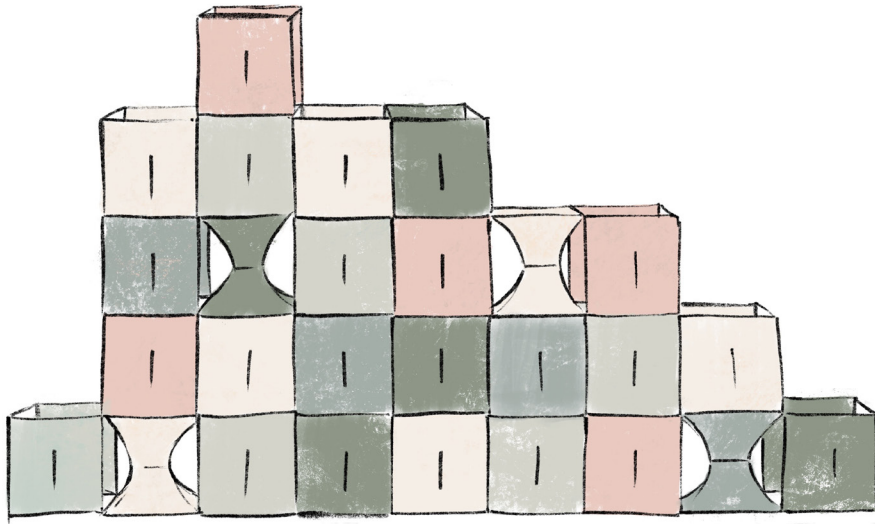
**Above:** Figure 57. Early trials of cube product concept. Uses SWA (Appendix A) wool yarn, 1 end, knit on a 14 gg machine at half gauge. Sarah Coxhead, *Cube product trial above funnel view*, 2022.



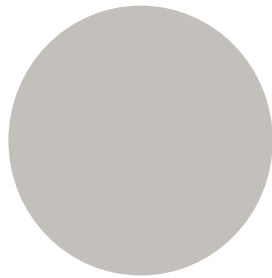
**Left:** Figure 58. Early trials of cube product concept. Sarah Coxhead, *Cube product trial side funnel view*, 2022.

**Facing page:** Figure 59. Sketches of cube wall concept with colour way ideas. Sarah Coxhead, *Cube wall concept coloured*, 2022.

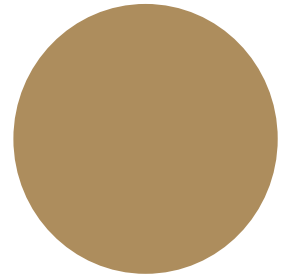
**Following spread:** Figure 60. The final 12 colours chosen from Imogen Tunnicliffe's colour palette for Autex Acoustics. Sarah Coxhead, *Autex Natural Fibre Palette*, 2023.



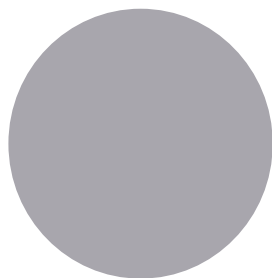
# Autex Natural Fibre Palette



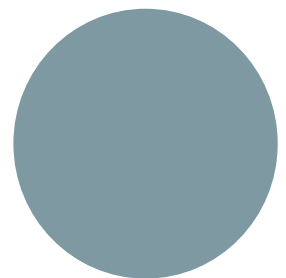
Matapouri  
13-5304 TPX



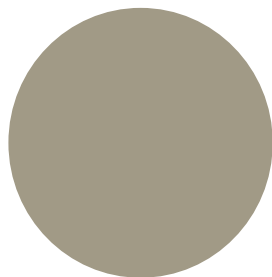
Kowhai  
16-1133 TPX



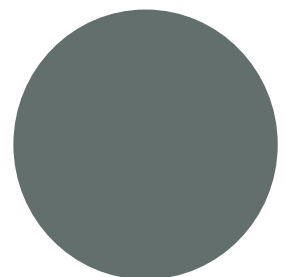
Cumulus  
15-0703 TPX



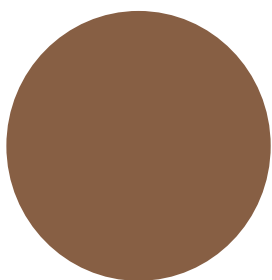
Half Bluff  
16-4404 TPX



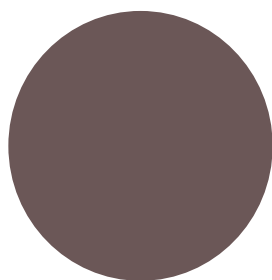
Clay  
16-1108 TPX



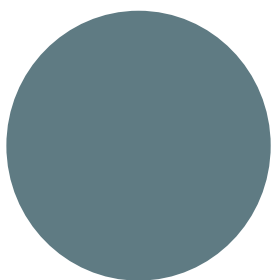
Iron Sand  
18-0510 TPX



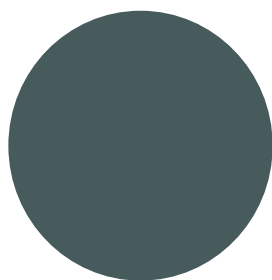
Karaka Berry  
18-1148 TPX



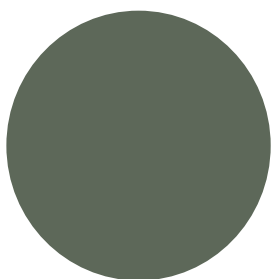
Puriri  
18-1415 TPX



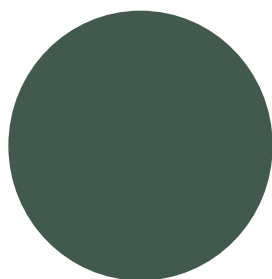
Bluff  
18-4510 TPX



Matariki  
19-5004 TPX

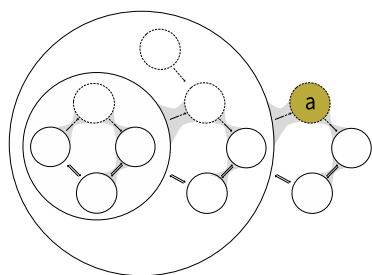


Half Kelp  
18-0420 TPX



Kelp  
19-0315 TPX

## RETAINING THE MATERIALS EXPERIENCE VISION IN PRODUCTION OF A COMMERCIAL PRODUCT



The manufacture of products at scale is not a space where materials experience is openly discussed nor understood. There is a tendency for technical sophistication to refine the product to a point where the Materials Experience Vision is lost. Manufacturers were quick to suggest how logos, branding, and stitch details could be added—which can be incongruous to the vision. With my engineering background, I communicated in Excel spreadsheets and simplified diagrams. Upon reflection, I feel it would have been better to communicate this vision more openly. A manufacturing mood board may have been beneficial to the process, so that everyone was on the same page with visual cues as to what was trying to be achieved.

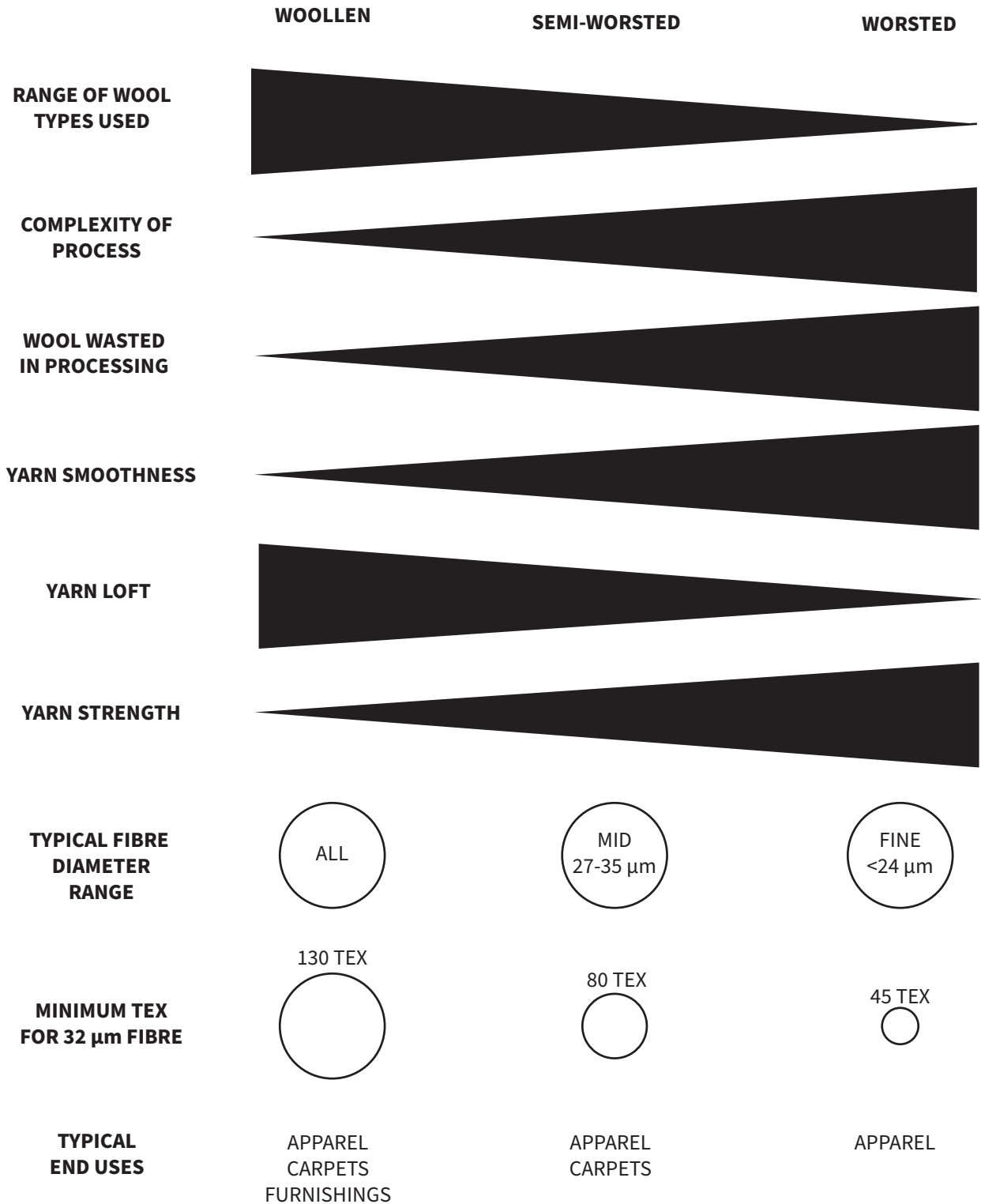
Another aspect of this phase was a realisation that both knitting and Strong Wool required a specific understanding of terminology and methods. I felt like a translator with a knowledge of languages that few in the room had. Effectively communicating the values and potentials of both Strong Wool and digital knitting became essential. The design of this communication became significant, too. How could I provide visual prompts that allowed more people to have the keys to these worlds of understanding?

So then a new materials experience vision evolved in my practice:

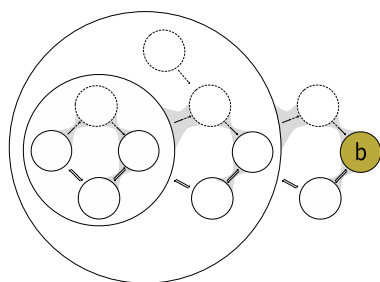
Strong Wool textiles, while having a heterogenous, changing nature with multiple potential failure points and issues to negotiate, have enormous potential. Through clear visual communications in manufacture, I want to demystify the process of manufacturing with Strong Wool. An example of this was my visual mapping of spin qualities (see fig. 61).

**Facing page:** Figure 61. Infographic visually communicating how the different spin processes compare. Sarah Coxhead, *Comparing Spinning Systems*, 2023.

# COMPARING SPINNING SYSTEMS



## MANIFESTING MATERIALS EXPERIENCE PATTERNS THROUGH TESTING





Fortunately, for the design of an acoustic object there is a way of quantifying the nurturing capabilities of the product through acoustic testing. Rather than being part of the prototyping process, this phase became an active element for the manifestation of the material experience.


Initially, I devised a list of parameters that I thought might influence acoustic absorption and considered how adjusting these might affect the acoustic absorption of the knitted Strong Wool. Swatches of these (see fig. 62) were tested in an impedance tube. The results could then be used as indicators of how the elements of proposed and future products might perform acoustically.


**Facing page:** Figure 62. List of swatches used to explore potential influences on acoustic absorption of knitted textiles parameters. Sarah Coxhead, *Acoustic Impedance Test Details*, April 2023.


# ACOUSTIC IMPEDANCE TEST DETAILS

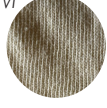
APRIL 2023



Investigating effect of cavity spacing		TEST#	Cavity spacings (mm):	
i		Washed	1	N/A single layer
			2	10
ii		140 TEX Woollen spun 3 ends	3	20
			4	40
		5 gg	5	50
		Unstretched	6	100
			7	100 with wool buds

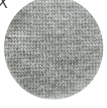

Investigating effect of stretch		TEST#	
iii		8	single layer
		1	for comparisson
		Washed	
		140 TEX Woollen spun 3 ends	
		5 gg	
		Stretched	

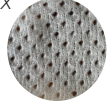
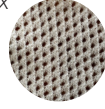
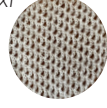
Investigating effect of washing		TEST#	
iv		9	single layer
		1	for comparisson
		Unwashed	
		140 TEX Woollen spun 3 ends	
		5 gg	
		Unstretched	

Investigating effect of spin		TEST#	
v		10	single layer
		11	for comparisson
		Washed	
		148 TEX Worsted spun 3 ends	
		5 gg domestic	
		Unstretched	

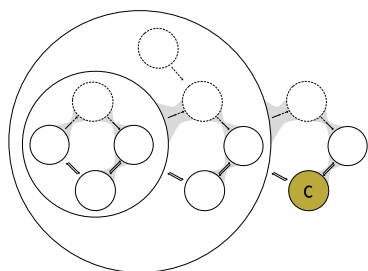
Investigating effect of thickness of knit		TEST#	
vi		11	single layer
		1	for comparisson
		Washed	
		140 TEX Woollen spun 1 end	
		8 gg	
		Unstretched	

Investigating effect of compressed folded knits		TEST#	
vii		12	single layer
		13	single layer
viii		11	for comparisson
		Unwashed	
		160 TEX Woollen spun 1 end	
		7 gg	
		Compressed	

Investigating effect stitch pattern architecture		TEST#	
ix		14	single layer links-links
		15	single layer interlock
x		11	for comparisson
		Washed	
		140 TEX Woollen spun 1 end	
		8 gg	
		Unstretched	

Investigating effect of mesh stitch pattern		TEST#	
ix		16	mesh density 1
		17	mesh density 2
x		18	mesh density 3
		11	for comparisson
xi			
		Washed	
		140 TEX Woollen spun 1 end	
		8 gg	
		Unstretched	

## DESIGNING THE FINAL EXHIBITION



In working with Autex Acoustics, I was keen to have a finished commercial product for exhibition. However, I also wanted this piece to speak to the elements of natural variability, my story of “Strong Wool Speaks,” and to the exploratory research with a less commercial format. My initial concept was a “conversation circle,” a metaphor for the conversation I had been having with Strong Wool throughout my research. This concept utilised an arrangement of our commercial panel design (see fig. 63).

Autex Acoustics rendered this in Rhino software and suggested I increase the height to improve the sound experience inside the circle (see fig. 64).

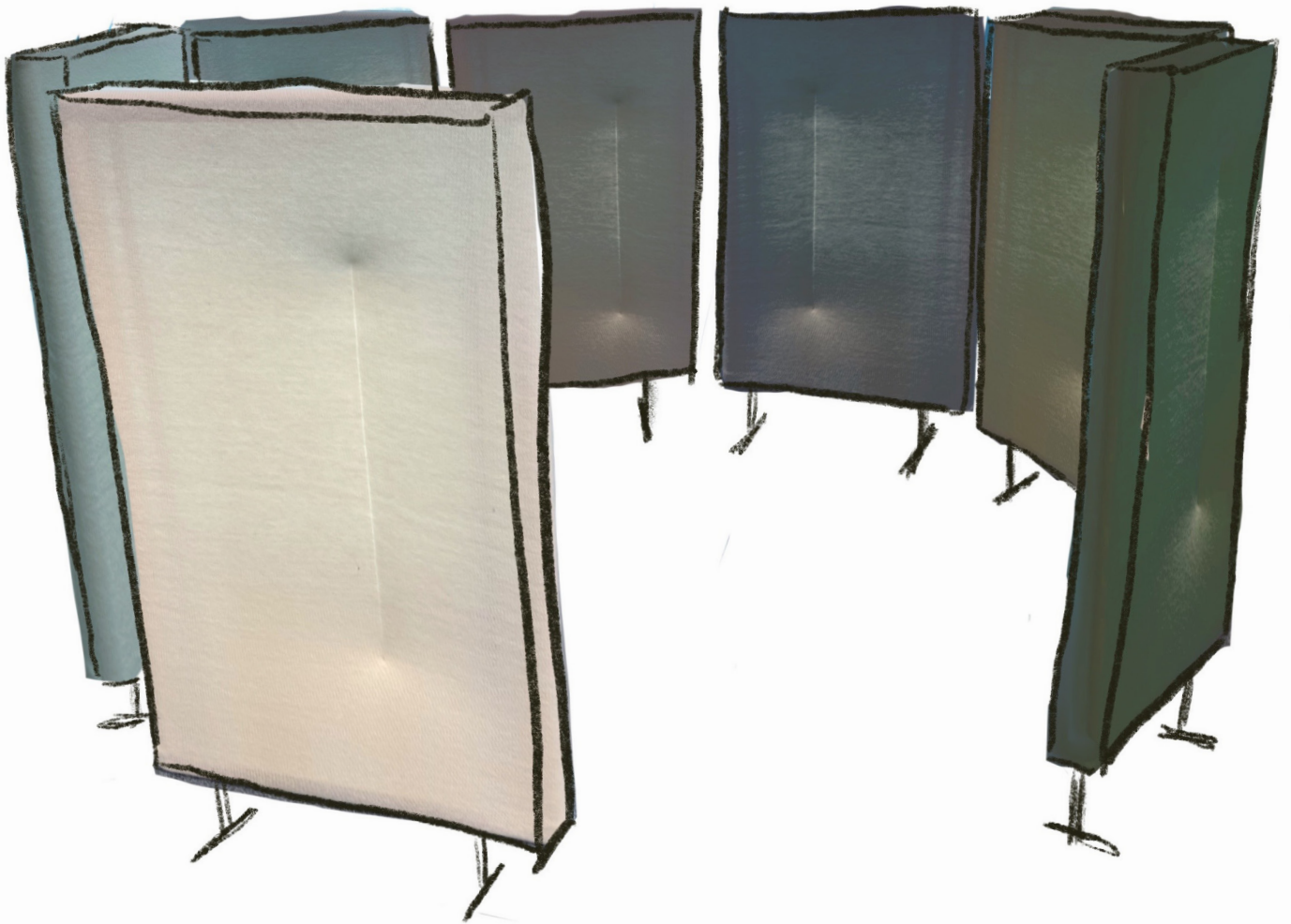
I then had a realisation that the space wouldn’t be enclosed and nurturing enough, so I suggested a form of closure where inside the circle a single commercial panel was placed. I also felt it lacked a natural variability that I had explored earlier in my research. I reworked the circular elements, creating more screens of a smaller width with various lengths of joins. I used a frequency spectrum of a sheep’s bleat captured from my iPhone (see fig. 65) to obtain a naturally derived graphic to provide a variability to the joins (see fig. 66).

**Facing page:** Figure 63. Sarah Coxhead, *Conversation circle concept*, 2023. Digital sketch.

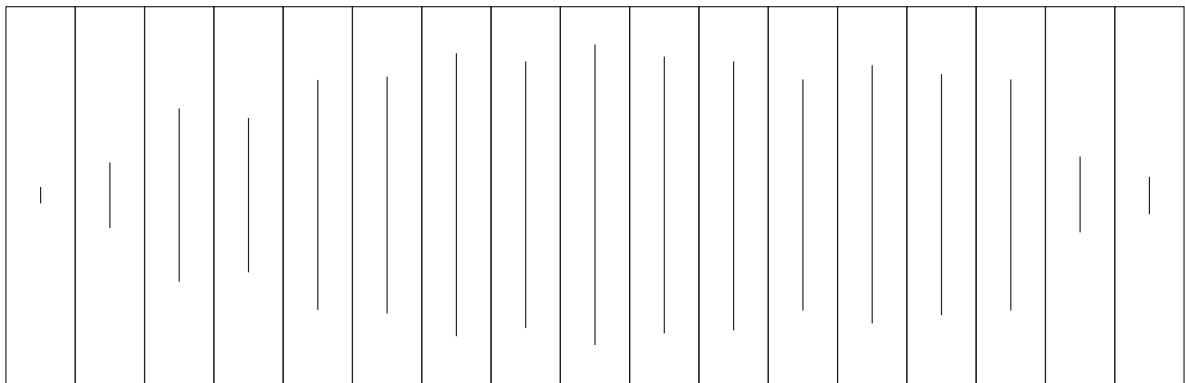
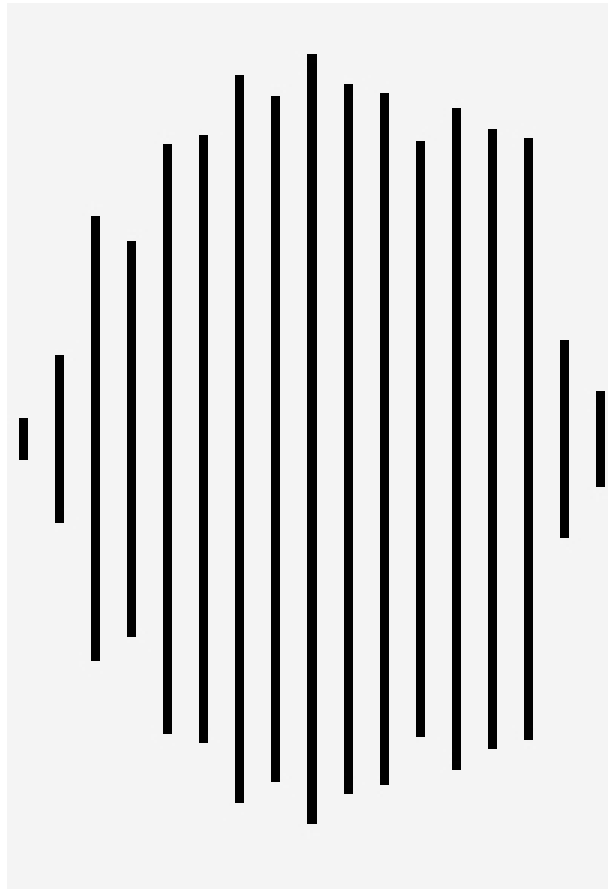
**Following spread, left:** Figure 64. Autex Acoustics visualisation of exhibition concept using Rhino software by Sam Wells, Autex Acoustics, 2023.

**Following spread, right top:** Figure 65. Sheep’s bleat frequency spectrum recorded on my iPhone voice memo application. Sarah Coxhead, *Sheep’s bleat frequency spectrum*, 2023.

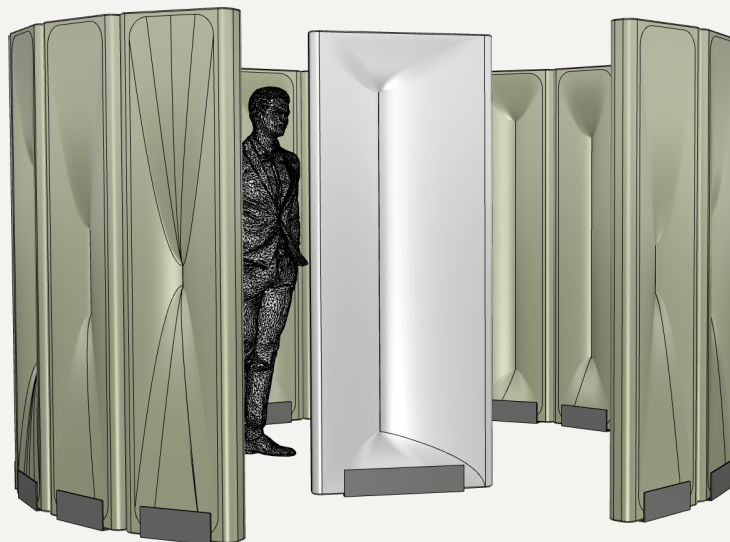
**Following spread, right bottom:** Figure 66. Layout of joins across the seventeen conversation circle frames, proportionally translated from the sheep’s bleat frequency spectrum. Sarah Coxhead, *Layout of joins for conversation circle*, 2023.





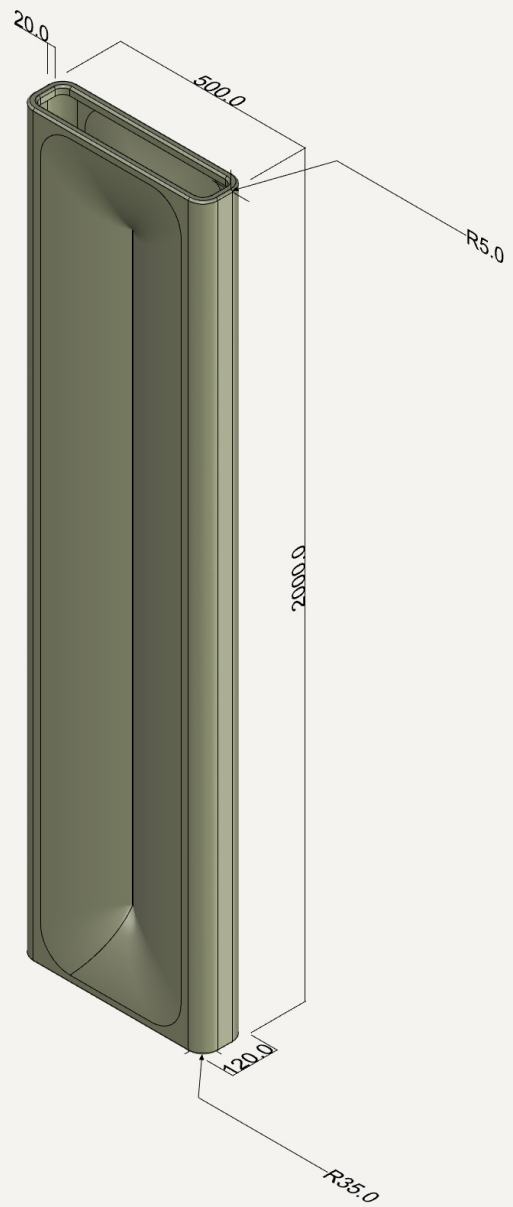
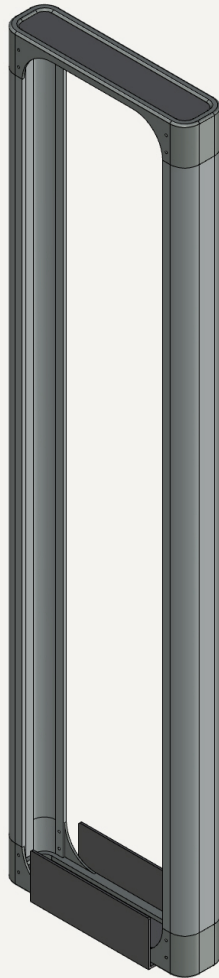
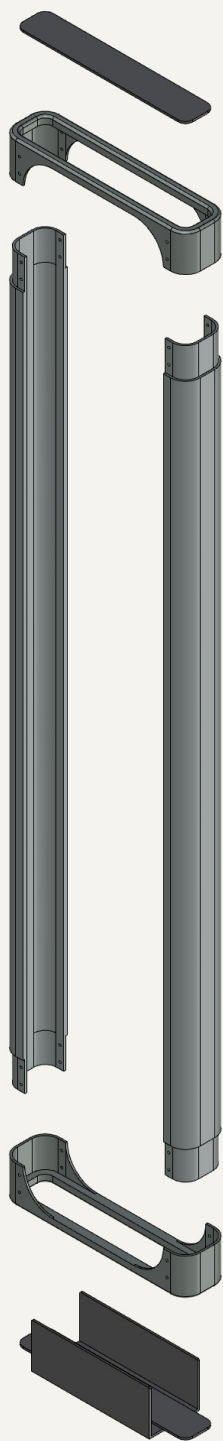


# Monolith Anti-Speaker Henge



3330.0





**Previous spread:** Figure 67. Rendering of the conversation circle (referred to here as the Anti-Speaker Henge) with concept for frame construction by Sam Wells, Autex Acoustics, *0076 Alternative Fibres*, 2023.

Subsequent to this a more sustainable frame material was discussed, with the metal frame being replaced by a wood and cardboard tube construction. Allowing for better acoustic properties and product end-of-life biodegradability. Using these materials meant that the cardboard was deformed by the tension created by the knitted textile, especially adjacent to the joints. There was an elegance and organic quality to the curve created, so while the cardboard tubes were taped to increase stability, they curve was retained. The cardboard's response to the knitted Strong Wool further amplifies the opportunities presented by a material-based design process.

The Conversation Circle could suggest a product concept, providing a break-out space in office environments where focused discussions can take place. However, I intended its purpose to be more of a demonstration of the potentials of the central design concept, it illustrates how variable design might be included as well as how multiple screens might be connected. Primarily it acts as a means of truly experiencing the fabric and its qualities.

The sound profile within the Conversation Circle is different from the surrounding space, and the nurturing qualities of the fibre are immediately appreciated. The acoustics inside the circle aren't muffled or deadened, the Strong Wool acts as an acoustic support, allowing for individual conversations to be heard within a crowded room. The visual and sensual qualities of the Strong Wool, knitted and tensioned to form curves, further support the experience.

**Facing Page:** Figure 68. Digitally knitted Strong Wool tensioned over cardboard tube and wood based frames. Sarah Coxhead, *Conversation circle and Anti-speaker exhibition piece*, 2023. Digital photograph.







**Facing Page:** Figure 69. Conversation circle, external view. Sarah Coxhead, *Conversation circle exhibition piece*, 2023. Digital photograph.

**Facing Page:** Figure 70. Sarah Coxhead, *Conversation circle and Anti-speaker exhibition piece*, 2023. Image Credit: Digital photograph, Paul Chapman.

## CONCLUSION

My research question is around understanding and amplifying the properties and values of Strong Wool through a material-centric textile design practice. This material understanding is gained through listening.

In first writing this question, I was focused on the more quantitative properties of Strong Wool. Its excellent acoustic absorbency, ability to filter air, its durability, and other valuable technical qualities were what I wanted to convey: I wanted my textile to scream aloud how Strong Wool is as technical as any synthetic fibre. Instead, through this research I have learnt to see that the world isn't as interested as it once was in the attention-seeking technical textile and that it is time for a new visual: one that soothes and inspires in its simplicity.

I have learnt to see Strong Wool as a biological heterogenous fibre: more than the yarn that arrives on a cone to be knit on a machine; more than the undesirable high-micron count that makes it coarse to touch; more indeed than the stories of its past glories as a highly prized commodity. I hear the many dialects of this fibre, how their needs and gifts differ.

Further research is needed to improve knowledge around the knittability of Strong Wool yarns. Research that is centred on the farm and follows a path directly to the machine. Embracing the notion of craft. Hearing its voice and speaking its stories at the micro, macro and systemic scales.

Listening to Strong Wool allowed me to engage in an alternative approach to the design of a knitted acoustic product. Learning how variations at the micro scale can affect Strong Wool's material properties provided a basis to search for alternative blends and spins of yarn, as well as allowing me to discuss these variations with spinners, manufacturers and my commercial partner, Autex Acoustics. At the macro scale, understanding contextual factors, environmental impact, and the social changes that impact how Strong Wool is experienced brought new perspectives to my practice.

The use of MDD was beneficial as a methodology for this research. Its focus on the material experience, understood primarily through practice-based characterisation, promoted deep engagement with what the material offers and how the world might look to act with this offering. As the research evolved, this material experience swept wide to include not only the consumer but also the producers. Strong Wool narratives became key elements of this journeying.

Strong Wool has much to say: its strengths and characteristics remain unchanged but we can help it tell its story in new ways. It is intrinsically warm, protecting, and comforting. As an acoustic panel, it provides these nurturing qualities: dampening chaotic environments, while being gentle on the environment. It became my job to do as little as possible to convey this. The success of the final product lies not in what we have done to the material but in how little we have done to it.

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# APPENDIXES

## APPENDIX A: Old Wool Yarn



Label information and rough thickness guide Wraps Per Inch: (highlighted yarns worked most effectively at half gauge on the 14 gg WholeGarment machine).

WPI: Wraps per Inch

TEX: The weight of 1000 metres of yarn

Tpm: Twists per metre of yarn with S and Z denoting the direction of spin

<b>Strong Wool Code</b>	<b>Yarn Count</b>	<b>WPI</b>	<b>Colour Name</b>	<b>Supplier</b>	<b>Notes</b>
SWA	N/A	28	N/A	N/A	30 µm
SWB	300/1 TEX	18	Spell	Wool Yarns	30 µm
SWC	N/A	21	N/A	N/A	30 µm
SWD	N/A	25	N/A	N/A	30 µm
SWE	125/1 TEX	21	Pampas	Wool Yarns	30 µm
SWF	215/1 TEX	20	Natural	Wool Yarns	30 µm
SWG	160/1 TEX	24	Agate	Wool Yarns	30 µm
SWH & SWI	N/A	21–18	N/A	N/A	30 µm
SWJ	N/A	25	N/A	N/A	30 µm
SWK	N/A	26	N/A	N/A	30 µm
SWL	N/A	26	N/A	N/A	30 µm
SWM	N/A	21	N/A	N/A	30 µm
SWN	N/A	27	N/A	N/A	30 µm
SWO	125/1 TEX	27	Dark Beige	Wool Yarns	30 µm
SWP	300/1 TEX	17	Beige	Wool Yarns	30 µm
SWQ	145/1 TEX	28	Dark Desert Storm	Wool Yarns	30 µm
SWR	125/1 TEX	35	Burgundy	Wool Yarns	30 µm
SWS	100/1 TEX	21	Maroon	Wool Yarns	25 µm
SWT	124 TEX	28	Blackberry	Wool Yarns	20 µm  80% wool, 20% nylon
SWU	124 TEX	31	Navy	Wool Yarns	20 µm  80% wool, 20% nylon
SWV	74/1 TEX	36	Graphite	Wool Yarns	25 µm
SWW	N/A	30	N/A	N/A	25 µm
SWX	119.05 TEX	35	Kingfisher	Knoll Yarns UK	Approx 29 µm, spinning twist 354tpm S, Folding twist 120tpm Z

## APPENDIX B: Machine Setting Findings

<b>Machine Settings</b>	<b>Approach</b>	<b>Notes</b>
Knitting speed	Reduce	The strain on the yarn is reduced
Needle hook sizes	Increase size	Part of initial machine set-up; larger hook size helps hold and release yarn correctly
Gap between beds	Reduce	If patterns use front and back bed simultaneously, a smaller gap places less strain on the yarn
Machine gauge	Increase	The machines at the AUT Textile Design Lab are 14 gg, designed for yarn much finer than even the finest woollen-spun Strong Wool yarn. Using them at half gauge allowed me to knit certain Strong Wool yarns on them successfully. A 7 gg or larger machine is preferable, however.

## APPENDIX C: Yarn Quality Findings

Yarn Qualities	Approximate Working Range	Notes
Linear density (indication of thickness)	160 TEX or less on 7 gg (half gauge 14 gg)	Each machine will have a TEX range, but the most reliable way of producing at scale is to have many thinner yarns (more “ends”) rather than one thick yarn, as breakages can be better managed.
Amount of spin	240 or more turns per metre	The tighter the fibre is twisted, the better the linear strength.
Spinning method	All can be accommodated	The spinning systems that result in a smoother stronger yarn are more effective in a knitting context. However, all can be accommodated.
Plying	More plies are preferable	The plying of the yarn strengthens it, but will also result in a thicker yarn.
Fibre blend	Long fibres preferable	The longer the fibres, the more strength. Woollen spinning equipment doesn’t handle longer fibre lengths well, so more appropriate for the worsted spinning systems.

