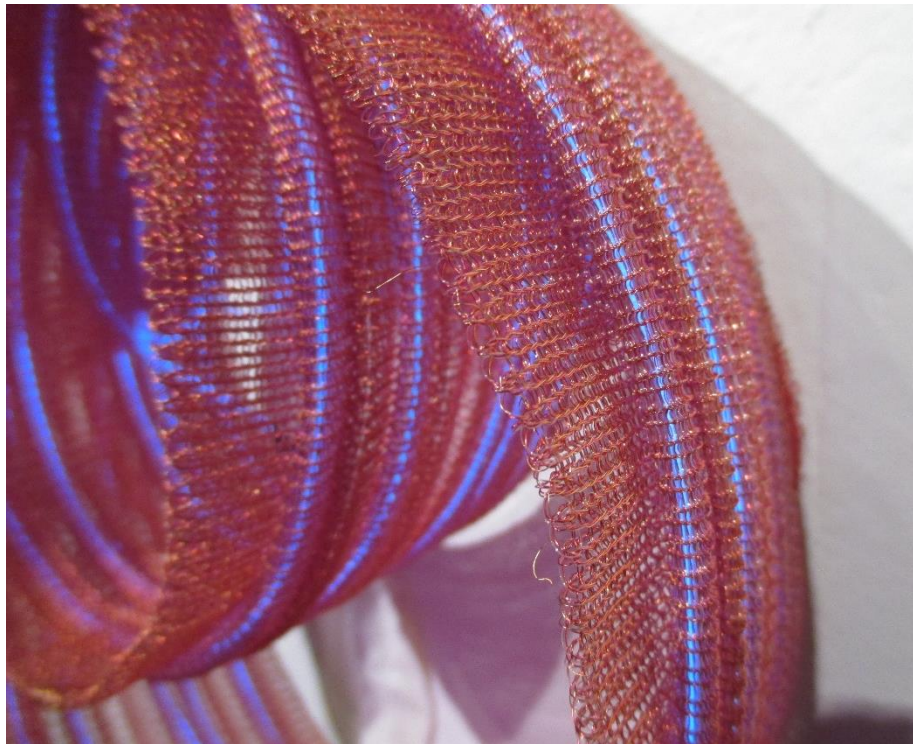# 3D Machine Knitting:

Composite Forms and Illumination

HyunJin Yun

This exegesis is submitted to Auckland University of Technology for the degree of
Master of Art and Design.

2014

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 nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made in the acknowledgements.

HyunJin Yun
May, 2014

Intellectual Property Rights

Acknowledgements

Table of Contents

Table of Figures

Abstract

This practice-led research process investigates the design and construction of innovative textile sculptures made from three dimensional (3D) knitted composite materials, and how their unique material, structural and textural qualities can be expressed through integration with light.

This project shows how established machine knitted 3D form and surface structure techniques can be learnt on manual, hand-flat knitting machines, translated through knit notation and design software, and produced on computerised and automatic knitting machine systems. Through this process, procedures to foster learning and research are discussed, and opportunities for creative design and innovation are identified in order to find a stimulating and productive work and research method.

In the course of this research, a range of 3D surface knit textiles and several 3D structured knit textile patterns were designed and fabricated with composite materials. The resulting pieces were tested for suitability as sculptural display and with the incorporation of micro-controlled electronic lights to create e-textiles.

The findings of this research suggest that unique and innovative textile designs can be created by experimenting and extending proven 3D knit techniques with different combinations of materials. The findings suggest potential applicability towards cross-disciplinary fields like engineering, architectural design, consumer products and artistic endeavours, as well as further research within textile design to explore new materials with the developing scope of 3D shaping techniques.

Keywords: textile design, 3D shaped composite material knitting, e-textiles, architectural and illuminated textiles.

Chapter 1

1.1 Introduction

This practice-led Masters Project conducts research into the design and production of 3D form and 3D surface knitted textiles made from composite materials. The resulting textiles will be exhibited as sculptural pieces incorporating electronic lighting. This exegesis provides a context for research and an explanation of the design choices and technical solutions used in the development of the 3D composite knitted textiles.

This practical research into composite material knitting and 3D knit shaping began on manually operated 'hand-flat' knitting machines. Once a selection of 3D form and 3D surface techniques had proven successful on the hand-flat, research began on developing these results further on a computer operated automatic knitting machine. This process required intensive study on how to use software that controls the computer-to-machine interface and 'translating' the knitting techniques from manual to computerised methods.

As well as showing how the technical challenges of knitting copper wire and thin monofilament together into a composite were successfully met, this research investigates how the resulting textile can be shaped and displayed to draw attention to unique 'self-structuring' knit forms, highly contoured textures and innovative aesthetic qualities. Other composite material combinations are also developed, produced as prototype structures and tested with electronic and natural light.

The selected academic literature review in Chapter 2 indicates that 3D form machine knitting is now a well-established field with a foundational range of proven techniques. More recent literature explores how innovation in knit design can be fostered and exemplified. In section 2.4 the work of inspirational designers provides a design aesthetic and vision for sculptural textile development, and the potential cross-disciplinary influence of 3D knitting from an engineering perspective is outlined. Chapter 3 first contains an explanation of the methodology that frames the research and how it fosters tangible research findings and insights, then covers project organisation, concept development, record keeping, and how solutions to technical challenges were assisted by the development of a knit notation system. Chapter 4 conveys the technical

research findings and design choices, including 3D form and surface techniques, the development of composite textiles, and how qualities of the sculptural prototypes can be emphasised with illumination. Chapter 5 is the conclusion.

By the end of this exegesis I hope to have explained how an in-depth understanding of knitting techniques combined with a comprehensive design methodology and thorough research procedures, stimulates the development of innovative 3D composite textiles on manual and computerised knitting machines.

C h a p t e r   2

2.1 Research Question

In textile design, the field of knitted fabric holds the greatest interest for me. At a fundamental level I remain intrigued by how a single length of yarn can be manipulated into a multitude of forms. In fact, the potential of machine knitting seems endless: different knit patterns, techniques, and equipment; various yarn types and the incorporation of additional materials; the shaping, use and display of the end textile. The opportunities to develop and innovate are infinite and highly motivating.

However, I cannot explore all avenues, so I have chosen to accelerate the trajectory of my previous work with textiles and light towards three dimensional knitting, and further my knowledge of combining materials to make unique composite fabrics. Therefore, after initial exploratory research and feasibility tests, the following research question was chosen to summarise, structure and guide the project:

How can I design and construct innovative textile sculptures made from 3D knitted composite materials, and then exhibit them in a way that expresses their unique material, structural and textural qualities through integration with light.

2.2 Research Aims

In this Masters Project I set out to learn new knit structure techniques, create innovative 3D form textiles with composite materials, develop the findings into design prototypes and produce light sculptures for exhibition assessment.

The primary aim of this exegesis is to map a path into 3D machine knitting possibilities. I hope to convey a sense of the fascination I experienced in the making of these 3D textiles, and explain the design and technical choices I made along the way.

The conclusive aim of this Masters Project is to exhibit finished sculpted textiles with integrated lights. I will develop the final pieces from the design prototypes shown in this exegesis over the remaining month until the assessment exhibition. I hope to display the finished pieces in an 'audience affective' way that exemplifies the textile surface

texture, the structural components within the fabric, and the 'illumination-translucidity-shadow' aesthetic expressed through their relationship to people, light and space.

2.3 Review of Relevant Literature

This practice based research project primarily draws on knowledge regarding 3D machine knitting. For the purposes of this study, influential academic literature on 3D machine knitting has been categorised into three areas: research into 3D knitting techniques and practical knowledge, research into 3D and seamless knit design and production systems, and research into 3D knitted textiles from an engineering background. Academic literature and design work relevant to other aspects of the research includes knowledge on the integration of electronics into textiles, the design of responsive fabric objects and their interaction with people, and the design of crafted lights.

Dr. Jenny Underwood's doctoral thesis "The Design of 3D Shape Knitted Preforms" is a foundational source for 3D knit construction techniques (2009). Underwood draws together information from books, academic references, industrial sources, and her own career as a technician and teacher. The thesis provides technical construction detail on a comprehensive range of 3D textured surfaces and 3D forms, as well as background information helpful to understanding the anatomy of knit structures. Underwood stresses that up to that time there were "significant gaps in current literature… in the area of 3D shape knitting" (2009, p. 22). Underwood also suggests that the common role division between technician and designer contributes to the lack of written 3D knit techniques; the technical knowledge generally being "learnt on the job" (2009, p. 22). Other researchers also indicate that this gap between design and technical knowledge impedes design innovation (Evans-Mikellis, 2011; Kalyanji & Joseph, n.d.; Sayer, Wilson & Challis, 2006; Smith, 2013; Yang, 2010).

Wonseok Choi and Nancy Powell provide a comparison between Shima Seiki and Stoll seamless knitting machines (2005). There is growing literature on the use of Shima Seiki seamless 3D technology from the perspective of designers. Designer Taru Arkko found that as 3D seamless technical requirements become more complex and sophisticated, it becomes even more important for the designer and technician to co-operate and communicate (2013). Designer and technician Sooyung Yang has

researched how the roles of knitwear designer, programming technician and machine operator can be combined for gains in efficiency and creativity (2008; 2010; 2014). Amanda Smith finds that designers who learn how to use the technical program can innovate directly to produce original knit designs (2013).

Studies on 3D knit fabrics from the perspective of engineering focus on measuring strength, auxetic expansion and other physical properties (Hu, Wang & Liu, 2011; Renkens & Kyosev, 2011; Ugbolue et al., 2010). They do not disclose the knitting techniques used to make the textiles that they have researched and they have only limited relevance to the development of 3D knit forms in this study. Nevertheless, their explanation of stitch ratio, composite yarn types and the application of Poisson's Ratio have proven useful, as have their demonstrations of 3D surface textured knit fabric properties.

The rise of e-textiles - the integration of lights and electronics into textiles - has opened new frontiers of interaction that designers are beginning to explore. Ramyah Gowrishankar studies how responsiveness can be built in to textiles to encourage curiosity and intimacy (2011). Joshua Edmison studies how sensors can be incorporated into textiles to detect and measure people's movement (2004). Marija Andonovska studies how textile designers can use electronics as a means of creative expression, and details various materials, components and methods to do this (2009).

There are countless designers who have chosen light as their muse and method. It is beyond the scope of this exegesis to survey their collections. However, the relationship between textiles and light – and how people respond to the effect of crafted light – has provided direction and inspiration throughout this project.

2.4 Contextual Knowledge and Inspiration

The following product and textile designers have been influential sources of information and aesthetic inspiration for this practical research project.

2.4.1 Janet Echelman

Figure 1: Echelman: "Her secret is patience", (2009).

At night, Echelman's sculptures appear to be made with woven light. The shape, volume and illuminated colour of the textile are all enhanced by the composition of the exhibition space which includes the flow of wind, people and external light (Echelman, 2009). The use of projected light is effective in showing the overlapping layers and folds. Despite its semi-transparent appearance and apparent fragility, the structure is made from PTPE (Teflon) fibre netting on a steel frame and is designed to withstand the sun and wind indefinitely (Echelman, 2009).

2.4.2 Issey Miyake
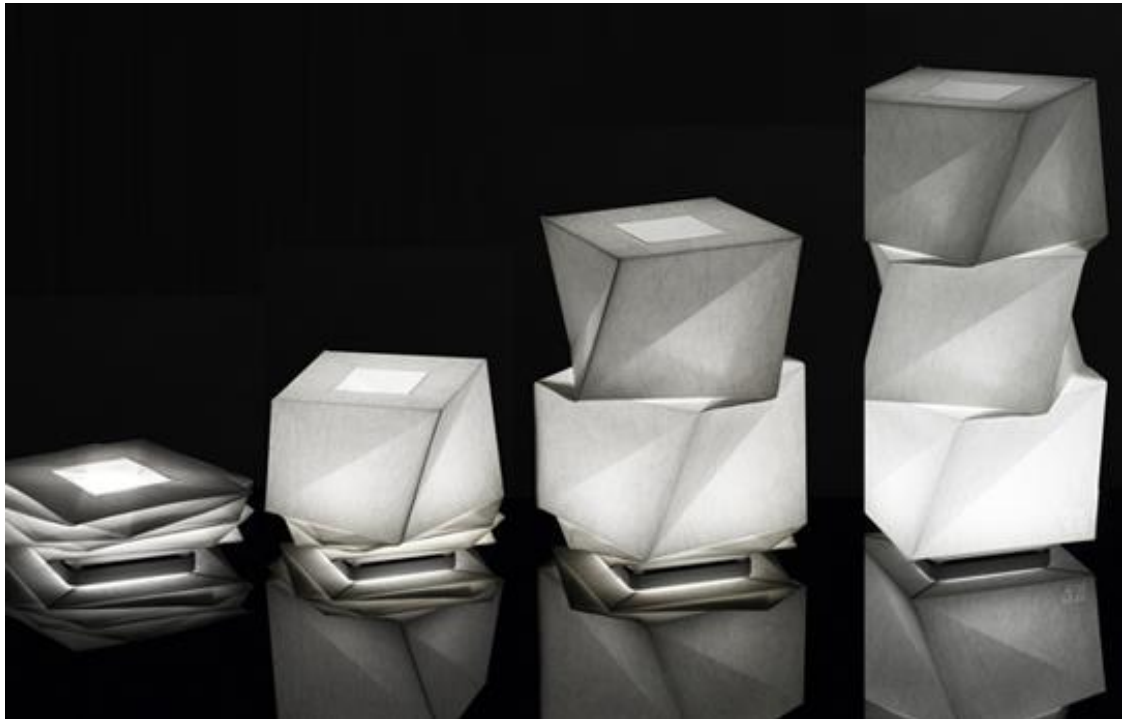
Figure 2: Issey Miyake, "Mogura" in the IN-EI lamp range (2013).

Miyake is a product and fashion designer known for his innovative use of 'origami' pleats and folds (Page, 2013). The origami light range "IN–EI" uses translucent, semi-ridged material that is constructed according to a mathematical ratio to unfold from flat into a structure with volume and texture (Wee, 2013). These folds create juxtapositions of light and shadow both within the object and in the projected light. Miyake's work has influenced my research and design, and can be seen in the paper models used to rapid prototype, on the 'origami-folds' 3D knitted textile, and on the light, shadow and translucent aesthetic developed in conjunction with electronic light.

2.4.3 Poisson's Ratio and Auxetic 3D Knit Fabric

An auxetic material is one that demonstrates the counter intuitive property of getting wider when it is stretched longer (Figure 3 and Figure 4). This kind of material is described as having a 'negative Poisson's ratio' (Hu et al., 2011). Several engineering studies examine negative Poisson's ratio in great detail, taking 3D surface folding knitted textiles as a subject (Hu et al., 2011; Renkens & Kyosev, 2011; Ugbolue et al., 2010).
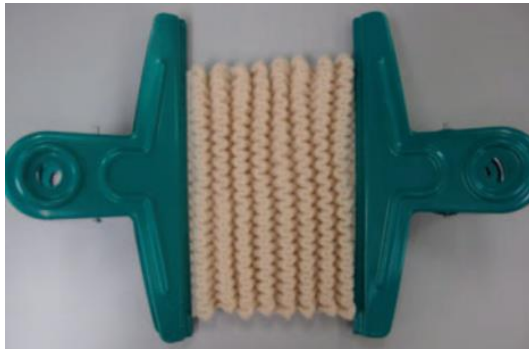
Figure 3: Relaxed auxetic 3D knit fabric (Hu et al., 2011, p. 1495).
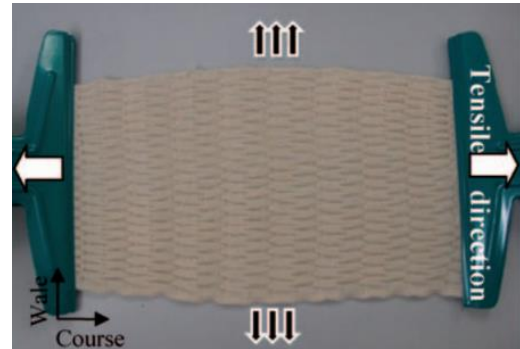
Figure 4: Auxetic 3D knit fabric stretched from left and right, showing simultaneous expansion top and bottom (Hu et al., 2011, p. 1495).

While the precise mathematics and strain data is not directly relevant to this study, I was interested by the aesthetics and demonstrated performance of the 3D textiles evident in engineering photographs. Interestingly, Underwood gives detailed instructions on how to knit technically similar 'surface folding' 3D patterns (2009, pp. 37, 79). Making the connection between engineering reference sources and Underwood's knit techniques enables the engineering data to have greater relevancy and applicability to textile design and construction.
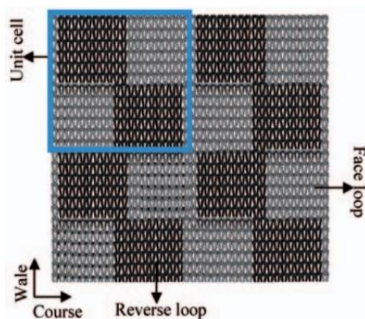
Figure 5: Pattern for the auxetic 3D knit fabric shown in Figure 3 (Hu et al., 2011, p. 1495).
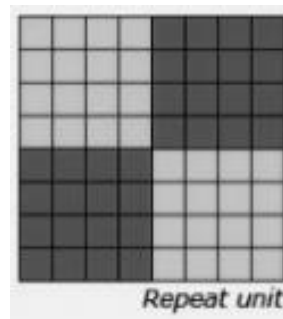
Figure 6: One 'cell' of the "Links-links" pattern shown in *Figure 7* (Underwood, 2009, p. 79).

Figure 7: An example of a "Links-links" 3D surface knit fabric (Underwood, 2009, p. 79).

2.5 Previous Work

During undergraduate study in 2011 I produced a 3D knitted sculpture made from acrylic yarn and illuminated with electroluminescent wire. I based the textile design on combination of the 3D 'ripples' technique taught to me by AUT technician Roger Colby, and Underwood's explanation of the 3D spiral form: "corn shape with suspending stitches" (2009, pp. 88-90). The textile was made with knit technician assistance at AUT Textile Design Lab on a Shima Seiki WHOLEGARMENT® knitting machine, and exhibited at the public event Art in the Dark 2011 in Auckland, New Zealand.

During Honours study in 2012 I was invited to join the AUT Dynamic Textiles Research Group to help make an e-textile dance costume. I made the textile structure on an industrial hand-flat knitting machine with monofilament yarn, and fibre optic strands were evenly inserted into the knit structure. Light from a LED source is carried by the fibre optic strands from the back, through the fabric and out to the tips, creating a fan of light around the dancer's hand.

Figure 9: Testing the illuminated knit and fibre optic textile for dance (Yun, 2012).

Figure 10: Testing the knit and fibre optic textile for dance (Yun, 2012).

For my 2012 Honours work I developed the monofilament and fibre optic textile further, adding metallic yarn and retro-reflective yarn. Arduino electronic micro-controllers were incorporated into the final pieces to control the intensity of the LED light. These final pieces were exhibited for assessment (Figure 11). The LED lights illuminate the fabric through scratches on the fibre optic strands. The knit fabric 'grips' the fibre optic between the courses, allowing the textile to be sculpted and shaped.
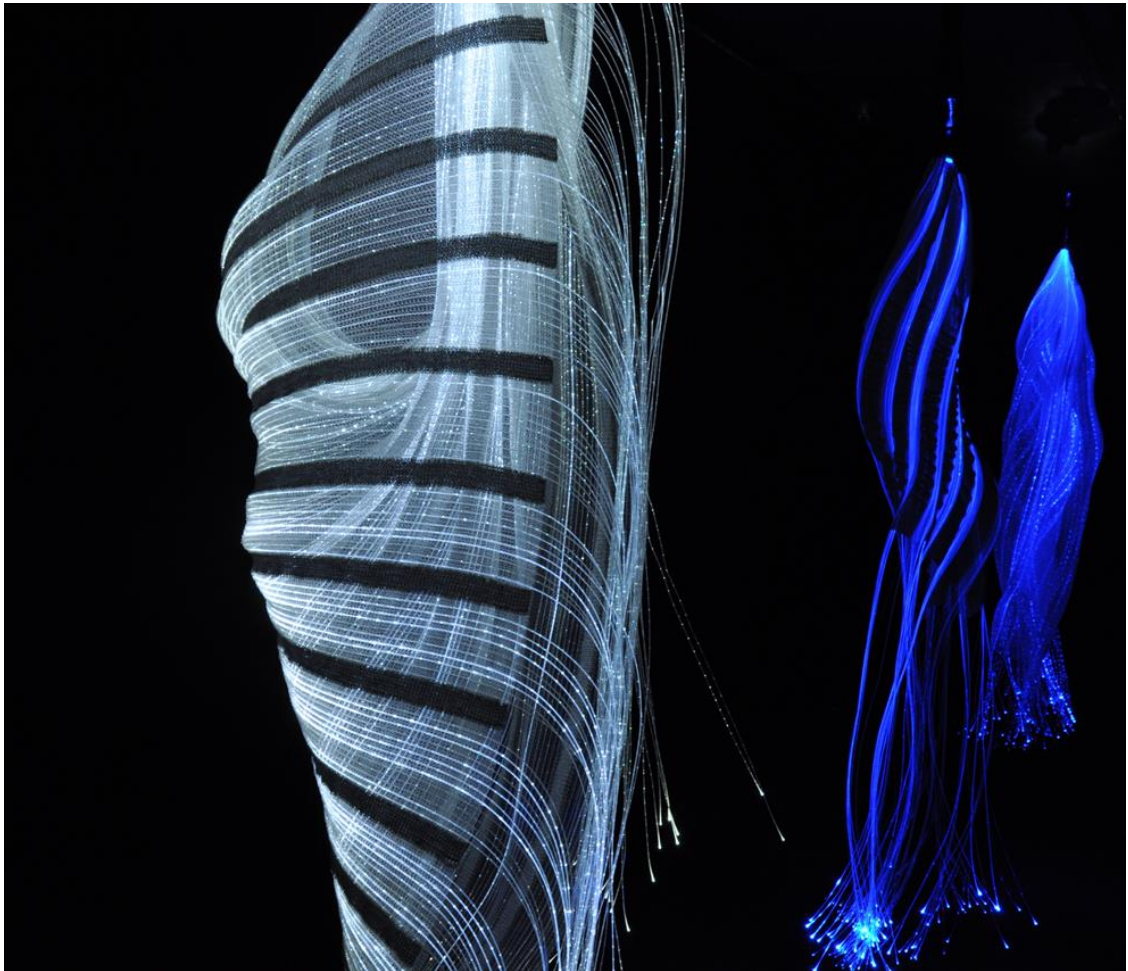
Figure 11: Reshapeable Knitted Light Sculptures (Yun, 2012).

Chapter 3

3.1 Methodology

This section outlines the methodology used to structure and evaluate this research project, and provides a theoretical framework to better relate this research project to other academic projects. In the chapter 'Research Process' I explain how I have worked from the research questions and project aims, through a procedure of inspiration, research, experimentation, problem solving, and development, towards the final goals of answering the research question and producing final exhibition pieces.

3.1.1 Methodology Requirements

The appropriate methodology for this project should provide an academically rigorous framework which describes and assists theoretical and practical research progression. The methodology must also account for the full context of the project including: initial contemplation; identifying research questions; practical development; and ultimately external academic appraisal.

3.1.2 Methodology Rationale

Action Research is a comprehensive methodological framework with applicability for theoretical considerations as well as practical development (Pinchen & Passfield, 1995). Schön describes Action Research as: "The process [that] spirals through stages of appreciation, action, and reappreciation. The unique and uncertain situation comes to be understood through the attempt to change it, and changed through the attempts to understand it" (Schön, 1983, p. 132). This spiral process matches the iterative process of conducting knitting experiments; a cycle of ongoing tests and improvements progressing towards the design goals and seeking to answer the research question.

Action Research prescribes flexible ways to think through, progress and understand practical research and one's own involvement in the process. McNiff explains Action Research as "practitioner based research" which is a form of "self-reflective practice" (2011, p. 8). In this way, the methodology includes the person undertaking the work as well as the work itself. Therefore the researcher must also be included in the research as

a participant (Smith, 2013, p. 70). This insight allowed me to consider how the research was affecting me as I was working on it.

Action Research is intrinsically flexible due to self-reflection and adaptation being integral components of the action spiral. This flexibility is applicable to the method itself as well as the research object (McNiff, 2011, p. 8). In fact, the practitioners are encouraged to adapt the framework to better suit their work (Mills, 2003; Zuber-Skerritt, 1995, p. 27). This allows for continual improvements to be made to the methodological technique as research progresses.

Action Research methodology is able to encompass the cyclical practical development process and the project framework as a whole. It provides a strong foundation for a practice based research to address practical and productive goals as well as provide for a reputable and rigorous academic structure. Its capacity to incorporate other research methods allows a flexible and nuanced approach that can be adapted to better fit the research project as it progresses. I have found its capacity to formally acknowledge my own presence in the research both creatively liberating (especially in planning for the exhibition) and helpful in writing this exegesis.

3.1.3 Methodology Adaptation
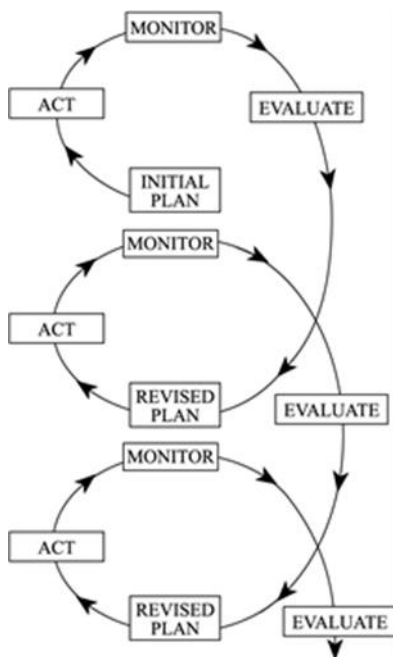
Figure 12: Action Research spiral (Kemmis, 1983).

The Action Research spiral was first formulated as a cycle of planning, acting, observing and reflecting by Kurt Lewin in 1944 (Bennett, 1995, p. 65). It has since been adapted into many different variations (Zuber-Skerritt, 1995, p. 12). As my research project progressed I realised a more nuanced breakdown would be helpful to explain in theory what I was doing in practice. Through further research into methodological theory I found that 'Action Learning' was able to provide another perspective on the research cycle process (Runco, 2003, p. 133).

The cyclical method of Action Learning is similar to that in Action Research. Zuber-Skerritt outlines a version of an Action Learning cycle described as

PDCA: Plan (the next stage from reference material and experimental data), Do (carry out the experiment), Check (the experiment data), Act (to improve the experiment or process) (1995, p. 12). The Action Research spiral model is similar to this cycle, but with greater emphases on reflection and overview (Zuber-Skerritt, 1995, p. 12).

The Action Learning method includes the theory that understanding research is a combination of 'programmed knowledge' such as that from authoritative reference material, and 'questioning insight' that the researcher gains from observation and reflection on experiments (Zuber-Skerritt, 1995, p. 6). This allows a research practitioner to study other researchers' findings and base trials on their results, as well as undertake novel and speculative experiments and learn from those results. In this context, innovation can be seen as the combination of established and new understanding.

Reflecting on the overall research methodology it became evident that Action Learning complements Action Research Methodology. Action Research provides a flexible framework that promotes practical and self-reflexive insights, Action Learning facilitates understanding based on existing and new knowledge, and their research spiral methods harmonise. Examining the research process through this dual lens allowed me to identify the practical 'design stages' in depth. This gave greater clarity in evaluating and reflecting on practical outcomes, and subsequently in explaining specific aspects of understanding in this exegesis.

3.2 Research Procedure and Process

The organisation of this exegesis may give the impression of a sequential progression from abstract concepts, through physical research to finished prototypes but in reality the project development was much more fluid. Research, conceptualisation and experimentation occurred throughout the project while working on solutions to design challenges. This is not to contradict the research spiral methodology – which acknowledges that the process of planning, acting, observing and thinking occurs at every level – but to affirm that progress occurred in a circuitous, back-and-forth manner towards the research aims.

Several procedures or strategies worked to improve progress consistency within the project. The comprehensive methodology stabilised and rationalised research progression, as did focusing on a well-defined technical area and a clear research

question. Establishing a process timeline (5.1.2) helped establish an expected order of stages, although progress was less sequential than it implies. Keeping a visual diary helped keep track of experimental progression, as well as showing overall progress. Concept drawings were also produced throughout the project. The process of visualising potential end results – of knit techniques and final pieces – helped with planning, direction and development.

3.2.1 Concept Drawings

Figure 13: Found leaf skeleton (Yun, 2014).
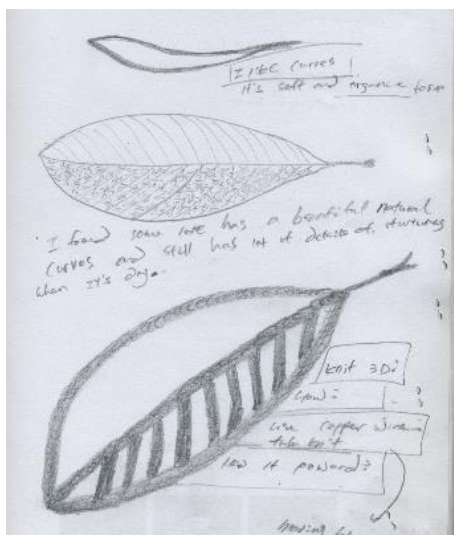
Figure 14: Textile concepts based on Figure 13(Yun, 2014).

Design concepts were an important aid to generate and record visual ideas. I do not find sketching easy but as long as I could visually represent the idea and capture it in an associated note the sketches I made were sufficient. Concepts are based on the research questions and design aims and refined from the experience of previous experiments. Concept inspiration (Figure 1) was sparked from researching literature, 'research browsing' images on the internet, or was developed from 'found objects' (like Figure 13) and the surrounding environment. Sometimes inspiration was not sought out but simply arrived in my mind spontaneously or while daydreaming.

As well as finding Janet Echelman's work inspiring, her philosophy of "taking imagination seriously" resonates with me (Echelman, 2011). While knit design can be very technical and sequential, imaginative visualisation – expressed in concept developments – allows expression of a more abstract creativity. This can lead to surprising breakthroughs and design advances, as well as providing motivating and relevant aesthetic ideas.

I continued to draw concepts over the course of the research. This led to the consideration of light, texture and shadow emerging as particularly important in planning the final exhibition pieces.

3.2.2 Concept and Development Modelling

Making 'cut origami' 3D models was a crucial tool in the design process. I found conceptual modelling complementary to drawing ideas and visual planning when it came to designing 3D structures. Figure 15 shows a model that helped me consider aspects of translucence and negative space. The models also helped me to consider the qualities of shape, light and construction. I made several models with paper and soft plastic to explore potential three dimensional structures. Modelling became less useful as the 3D knit structures were developed into prototypes. The speed of knitting on the Shima Seiki makes rapid prototyping faster than modelling.

Figure 15: Plastic 3D model from side and front (Yun, 2014).

Figure 16: 3D paper model based on Figure 15 (Yun, 2014).
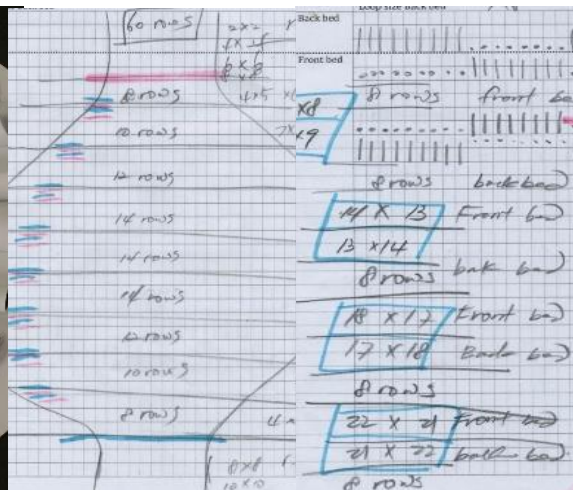
Figure 17: Plan for knit structure action (Yun, 2014).
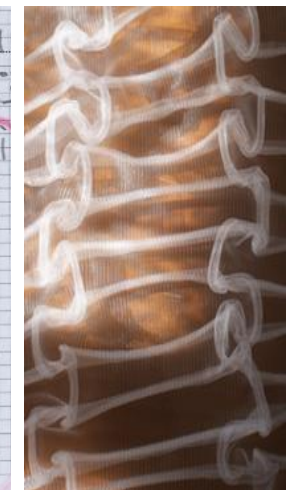
Figure 18: Repeatable pattern for knitting (Yun, 2014).

Figure 19: 'Leaf' prototype textile experiment (Yun, 2014).

3.2.3 Visual Diary

The visual diary is a collection of physical and digital documents. It includes concept drawings with notes on development; pictures from magazines, scans from books, and pictures found online. It also contains a record of experimental planning notes as well as data and analysis of experiments. A visual diary is helpful for Action Research reflection, especially for reviewing the design processes and analysing how the project is developing in part and in whole.

I have a digital record of (now over) 3702 photographs taken during the research project. Photographs are a useful way of retaining visual data while condensing experiment results (Prosser, 2010, p. 123). Examining photographs was a key application of 'observation' and 'reflection' based on the research spiral. They also aid exegesis explanation and provide technical and aesthetic 'proofs'.

The notes taken while developing techniques on the hand-flat knitting machines became especially useful when translating these results to the Shima Seiki SES122-S.
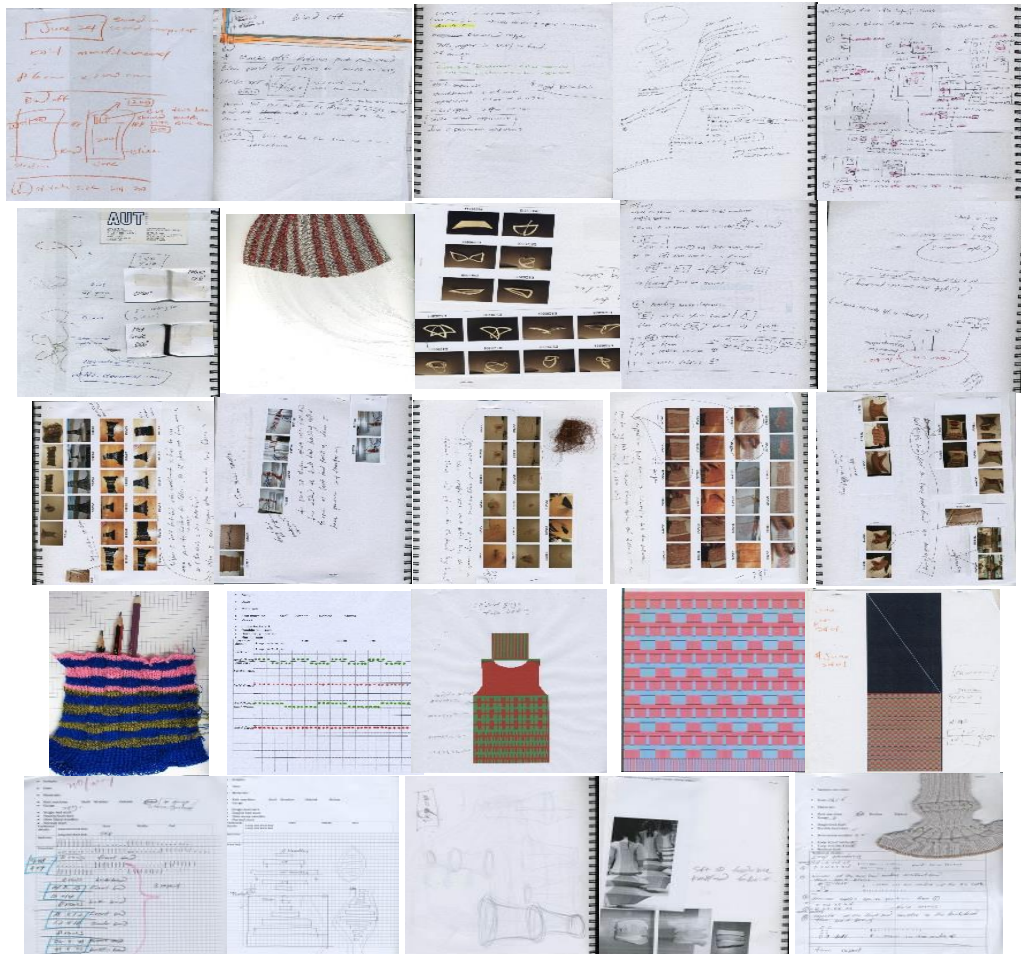
Figure 20: A selection of visual diary documentation (Yun, 2014).

3.2.4 Knit Design Notation

Five different knitting machines have been used over the course of this project (see Appendix 5.1.4). It is usually simple to move knitting techniques between hand-flat machines. However moving from hand-flat to the Shima Seiki SES122-S computerised machines was a significant logistical and intellectual challenge. For a start it required an organised approach so that techniques and experimental data established on hand-flat machines could be 'translated', through the Shima Seiki SES122-S computer system, and replicated on the automated machine. To assist in this process I created the following knit notation template.

Figure 21: A template of "sample" pattern with a similar textile (in 8 by 9 ratio), coloured to show corresponding areas to pattern (Yun, 2014).

3.2.5 Shima Seiki Computerised Knitting Machines

The Shima Seiki SES122-S (abbreviated to SES122-S) is the only Shima Seiki machine in the Textile and Fashion department at AUT. The more advanced Shima Seiki WHOLE GARMEMT® (abbreviated to WG) machine is sequestered at the busy, semi-commercial Textile Design Lab where the technicians are knowledgeable and helpful but have many demands on their time.

When access to the WG machine became restrictive, I chose to use the SES122-S almost exclusively. This proved to be a blessing in disguise. The gruelling learning curve this involved forced me to learn quickly. Other advantages of using the SES122-S are that it was easier to access including after hours, and its use is unmediated by knit technicians. This meant that I could have full control of design, development and programming, and could see results immediately rather than being dependent on a technician's schedule. In terms of method this allowed a rapid 'research spiral'. From a practical point of view it meant a rapid prototype process, as I could design, knit, evaluate and analyse quickly and repeatedly.

This quick turn-around was especially important as I essentially taught myself to use the SES122-S effectively. This was a frustrating and challenging experience to begin with, but once I could understand some of the basic methods and conventions the process became more like a challenging puzzle to solve. Becoming familiar with the Knit-Paint program was crucial, which I learnt through trial and error, undergraduate notes, and tips from my supervisors and AUT technician, Roger Colby. The basics of the Knit-Paint software are relatively simple, but the full scope of the program is vast. "The Knit-Paint program is where all technical knit programs are constructed, processed and checked" (Underwood, 2009, p. 43). Determining how to program Knit-Paint to perform the knitting that I understand intimately on a hand-flat was the greatest challenge of this project.

At first I was not even sure that hand-flat techniques could be knitted in the same way on an automated system. Learning to use Knit-Paint was a process of gradual comprehension and eventual relief as I realised that technical crossover was possible and how that translation could be performed. To this extent I can relate to Smith's experience who, being proficient at translating knit patterns into stitch architecture instructions and pattern notation, "came to realize that Knitpaint is only another version of these scripted instructions" (2013, pp. 94-95).

The Knit-Paint system represents and interfaces exactly with how the stitches are constructed on the automated knitting bed. Therefore I only used the Knit-Paint program as it allows a graphically mediated, one-to-one relation to the physicality of the knitting. The implication of this is that designers must understand how the Knit-Paint graphical representation relates directly with the mechanical reproduction of stitch architecture if they want precise control over knit textile design on the automated system.

The Knit-Paint program has a 'Work' page where knit patterns are drawn in a visual representation. Once the Knit-Paint interface and conventions are learnt, knit patterns can be designed in this graphical notation. To use Knit-Paint to design intentionally (rather than creative trials to see what happens), an in-depth understanding of stitch architecture and knit form structure is required. In this regard, my experience on the hand-flat machines was invaluable.

When using Knit-Paint to conduct creative trials and explore potential techniques, a trial and error process of design, production, observation and 'reverse engineering' can be helpful. This involves programming the experimental sample in Knit-Paint, using 'knit simulation' to confirm that the machine can knit it, fabrication of the sample on the machine, and then analysing the stitch architecture of the sample to try to retrospectively understand how the result exactly relates to the Knit-Paint notation that was programmed. I used this method extensively to progress techniques beyond what I had learnt on the hand-flat machines.

Chapter 4

This section covers the main 3D knit techniques that I focused on, as well as how I used materials and the choices I made along development paths.

4.1 Composite Knit Textiles & 3D Knit Techniques

4.1.1 Monofilament

Figure 22: Plain stitch or 'Jersey stitch' of single knit on the top and 3D structure knit on the bottom (Yun, 2014).

Knitted monofilament fabric is light, strong and flexible. I found that I could knit a whole bed width and it will stay wide and resilient. Monofilament has a high degree of 'memory' in that it tries to return to a straight line. This property gives knit monofilament dynamic elasticity: the tensions within each series of stitches are much more evident. This has significant bearing on 3D knit forms as it is the tensions within the stitch architecture that cause a larger form to twist and shape. Figure 22 shows that in the stitch architecture of jersey stitch, monofilament will curl up into itself completely from the top and bottom, while remaining virtually the same width as when knitted on the machine. The resilient tension within monofilament means that it performs well when knitted with varying stitch architecture.

4.1.2 Copper

Figure 23: Plain copper stripes knitted on the Shima Seiki SES122-S (Yun, 2014).

Figure 24: Placing spools of monofilament and copper on the floor can help avoid kinks and tangles when knitting (Yun, 2014).

Copper snaps very easily when knitted alone because it has a low tensile strength. A solution is to knit it in combination with another yarn, so that together this becomes a composite yarn (Underwood, 2009, p. 10). Monofilament works well with copper. The high strength of monofilament protects the copper and the high tensile tension encourages 3D shaping while the colour of the copper is only minimally affected.

Copper and monofilament easily tangle when knitting. Placing the spools on the floor helps the yarn unwind more evenly, and gives more room for the knitter to notice kinked yarn approaching the yarn feeder and yarn carrier. Note that despite all best efforts, copper and monofilament still snap far more often than cotton or wool.

4.1.3 Retro-reflective

Figure 25: Monofilament knit with 4 rows of 0.3mm wide retro-reflective ribbon (and monofilament) at top and 2 rows below (knit on the Shima Seiki SES122-S) (Yun, 2014).

Retro-reflective yarn (technically a fine ribbon) has the unique effect of strongly reflecting light *but only precisely back towards the origin of the light.* This means that in order to observe the special strong reflection, one must view the retro-reflective from directly in front or behind the light source. The effect is especially evident in photography with a flash. Retro-reflective yarn is even weaker than copper and so must always be knitted with another yarn for support or it will almost certainly snap within a few rows.

4.1.4 Fibre Optic

Figure 26: Fibre optic strands inserted through a 3D ripple structured copper composite on the left and a separate double knit copper composite piece on the right (Yun, 2014).

Figure 27: Twisting bottom of the fiber optic bundle to put inside of the fabric for a shaping (Yun, 2014).

Figure 28: Fiber optic and copper knitted fabric shaped (Yun, 2014).

Fibre optic strands cannot be used as yarn because they are too inflexible and brittle to knit (Yun, 2012, p. 41). However individual strands of optical fibre can be inserted or "interlaid" between the V-beds of a hand-flat knitting machine to become 'sandwiched' between the row of stitches in a course of double knit fabric (Peterson & Sandyik, 2009).

An advantage of this method is that the knit fabric can slide along the strands. With a tight stitch tension the knit 'grips' the strands. This allows the fabric to be stretched or compressed meaning the fabric can be shaped on the 'skeleton' of the strands.

The insertion of fibre optics into knit courses has potential to be developed much further with 3D knit techniques. Combining shaped knitting with fibre optic has been attempted on a STOLL CMS 330 TC and is theorised as more likely to succeed on a Shima Seiki SWG-X (Peterson & Sandyik, 2009).

4.1.5 Ripples
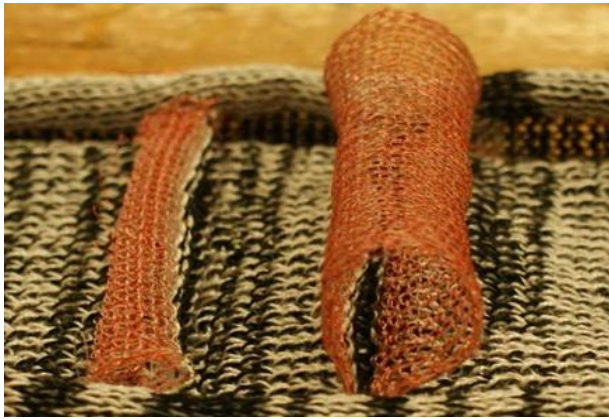
Figure 29: Test showing two sizes of ripples or 'rolls' of copper and monofilament attached to a cotton double knit backing, knitted on a hand-flat (Yun, 2014).

Figure 30: Ripple on the lace structure of composite structure and material knit (Yun, 2014).

Figure 31: This series of small ripples were knitted on the SES122-S using copper and monofilament (Yun, 2014).

This 3D form structure is a combination of double bed knit 'backing' and single bed 'ripples'. It is constructed after a row of double knit by putting the needles on one bed into rest position, knitting single bed to the desired ripple size, then joining with the double knit again.

Although Underwood does not mention the ripple technique in her 2009 thesis explicitly, the 'suspended stitches' technique has similarities, including controlling the width of the shaping and the diameter of the shape: "Generally more courses knitted the more raised and 3D the fabric surface is" (Underwood, 2009, p. 135). Ripples can be knitted on the Shima Seiki and hand-flat machines.

4.1.6 Ripples with Fibre Optic

Figure 32: Copper and monofilament ripples (red) between monofilament and acrylic double knit (flecked grey) containing interlaid fibre optic strands (straight white strands), knitted on a hand-flat (Yun, 2014).
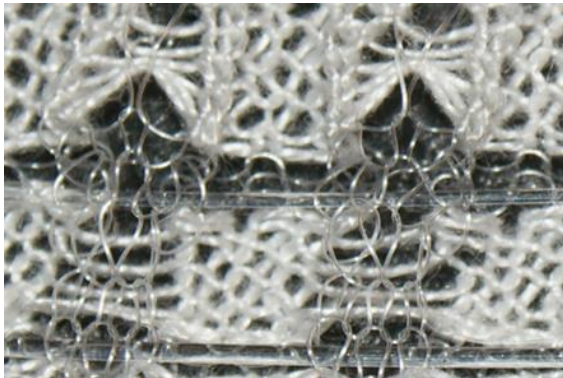
Figure 33: Cotton and monofilament combination yarn 'tuck stitch' lace with fibre optic interwoven between double knit courses on hand flat (Yun, 2014).
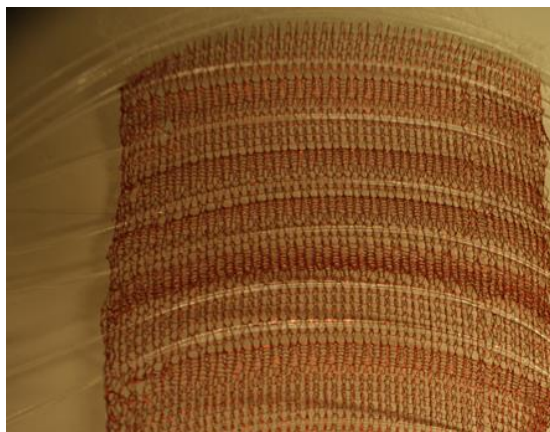
Figure 34: Monofilament and copper ripples (dark strips are ripples) texture knit with fibre optic interwoven (Yun, 2014).

It is possible to incorporate fibre optic strands and 3D ripples by combining the methods in 4.1.4 and 4.1.5. This allows the ripple volume and form to be supported and shaped on a fibre optic framework (Figure 32).

This finding proves that full 3D forms can be knitted with composite material and be combined with fibre optic strands in the one textile.

If a reliable way could be developed to insert fibre optic strands using a Shima Seiki, this would allow highly advanced combinations of fibre optic and 3D shaped fabrics to be produced. While it is technically possible to do this on a hand-flat, the time required to manually construct this combination textile makes it only feasible for small scale production and unique items.

I intend to extend the 'composite material with interlay method' research one more level before the exhibition. I will investigate the insertion of high tensile, high memory wire into knit courses. If successful, this would allow a much more pronounced shaping skeleton. I would apply this technique to the final piece 'Why Does the Moon Follow Me' (see 4.3.1) to create a spherical frame.

Figure 35: Two rows of thick yellow monofilament knit with other yarns. No frame used; self-supporting (Yun, 2014).

When I imagined knitting with thick 0.3mm monofilament I was expecting the monofilament knit rows to expand more than 0.12mm monofilament but evenly along the course. Instead, the monofilament twists in unpredictable patterns and gives more organic shapes, even though it is knitted with regular rows and tension (Figure 35). Further tests are required to determine whether this is caused by the composite type, the thicker yarn in the same pattern, or an anomaly in the stitch architecture or tension. This experiment shows that there is much room for further research into the properties and possibilities of using different kinds of monofilament and in different

Figure 36: Tan acrylic with rows of monofilament and red acrylic composite. Relaxed (Yun, 2014).

Figure 37: Same sample as Figure 36. Stretched (Yun, 2014).

composites.

Figure 36 also uses 0.3mm monofilament in combination with red acrylic, however you cannot see it because it curls up on itself over at least four rows. Figure 37 shows the same sample stretched out. This regular but more pronounced shaping was more in line with prior expectations.

The result that thicker monofilament curls more than thin could be experimented with further to find new 3D folding surface patterns and 3D forms. It also has implications for strengthening composite combinations. The irregular and unpredictable curling evident in Figure 35 could be investigated as a way of generating creative and organic forms within composite knitted textiles.

Figure 38: Thin cotton and composite 0.12mm copper stripes, knitted on 8 gauge hand-flat (Yun, 2014).

Figure 39: The same piece as Figure 38 but resting on the ground (Yun, 2014).

Figure 38 is a tubular form, knitted to the same number of stitches all the way down. Here one can clearly see the difference that adding copper to the cotton makes.

Thin cotton is used throughout this test piece, but every alternate stripe also has 0.12mm copper added to make a composite mix. The bulging curves are created by stretching out the finished fabric. The malleability of the copper holds this shape while the cotton tightens up.

Figure 39 is the same piece resting on a table. The cotton alone collapses but the copper composite holds the shape. This has the potential to be developed to fold flatter, similar to Miyake's IN-EI lamps.

Thicker copper holds shape with better definition, strength and durability (Figure 40 and Figure 41). It will stay shaped longer, and is more reshapeable without damaging the fabric. This property of copper shapeability adds potential variation to otherwise consistent 3D structures.

Figure 40: 0.3mm copper and cotton, knitted on 3 gauge hand-flat (Yun, 2014).
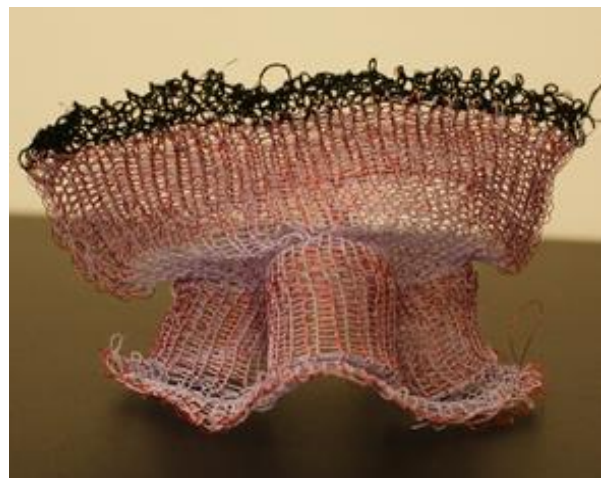
Figure 41: 0.3mm copper and cotton, knitted on a3 gauge hand-flat (Yun, 2014).

4.1.7 3D Surface Texture

It is a finding of the research that understanding stitch architecture in combination with knit technique knowledge directly aids 3D structure design innovation. Known as "stitch architecture", combinations of different patterns, ratios and stitch types can create an "infinite array of three-dimensional surface patterns" (Underwood, 2009, p. 78). Investigating this technique through multiple experiments revealed that only certain

Figure 42: Low ratio "curve" links-links pattern (Yun, 2014).

Figure 43: "Curve" links-links pattern showing high ratio (Yun, 2014).

Figure 44: "Curve" links-links pattern showing non-3D ratio (Yun, 2014).

ratios result in 3D surface structures (See Appendix 5.1.9). This is because stitch ratio is one cause of yarn tension in the stitch architecture, and it is this stitch shape tension that gives rise to 3D surface structure.
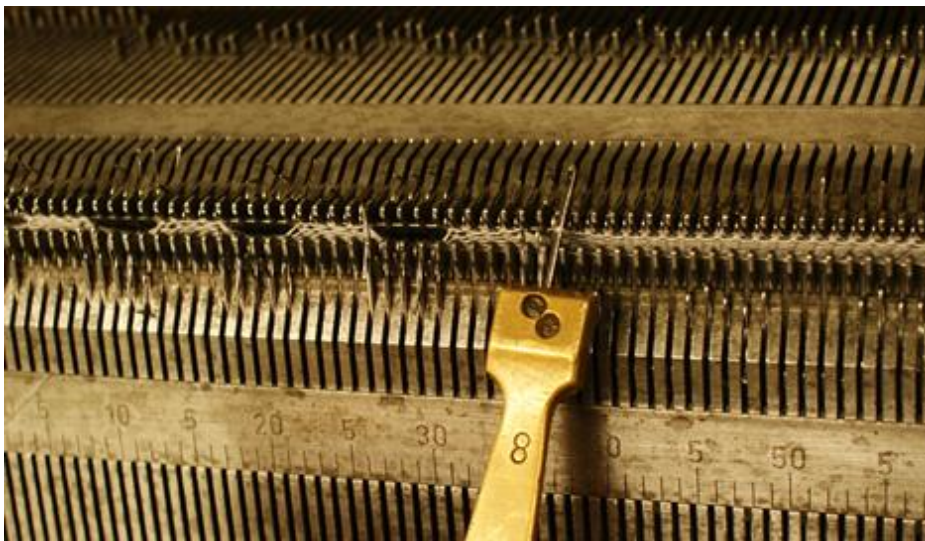
Figure 45: Loop transferring on the hand flat (8G) machine (Yun, 2014).

3D surface texture patterns can be made by patterns of purl and knit loop transfers from the front bed to back and vice versa. Carrying out this technique on the hand-flat is painstaking and time consuming. Applying these techniques on the Shima Seiki SES122-S dramatically increases productivity and therefore the range of potential outcomes from experiments.

Figure 46: Wool (Yun, 2014).

Figure 47: Wool (Yun, 2014).

Figure 48: Wool (Yun, 2014).

These experiments are based on the connection between Poisson's ratio and Underwood's explanation of the 'links-links' technique. They are the results of experiments exploring how pattern ratio changes give rise to a variety of 3D structured surfaces.

These experiments reflect a stage of greater familiarity with Knit-Paint and the SES122-S where I could rapidly plan and produce textiles. At first it was difficult to get the results I intended due to making programming mistakes, but with experience I was excited to find I could program with the ease of knitting on a hand-flat but without the arm work.

After this series of experiments I moved to bigger scale prototyping and varied 3D surface *structure designs.*

29

Figure 49: 3D structure (Yun, 2014).

Figure 50: 3D structure (Yun, 2014).

Figure 51: 3D structure (Yun, 2014).

This series of 3D folding surface experiments were designed to explore a range of varied, creative and dynamic structures. Small scale samples do not give an accurate impression of how the textile will shape and drape as a large sculptural piece. This realisation led me to knit bigger 3D structure samples. Larger samples also manifest 3D surface forms differently. Going on the successful results from this series of experiments I became confident to knit with the more expensive monofilament and the very expensive copper on the Shima Seiki SES122-S.

Figure 52: 3D structure (Yun, 2014).
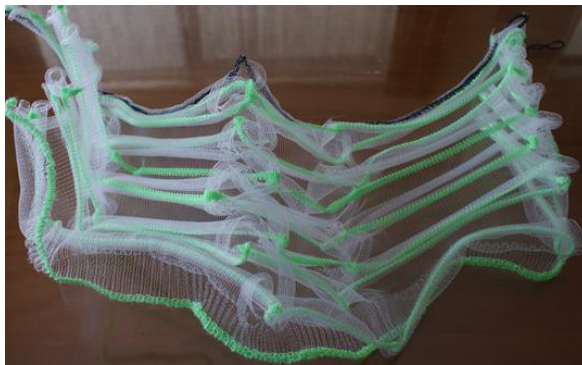
Figure 53: 3D structure (Yun, 2014).
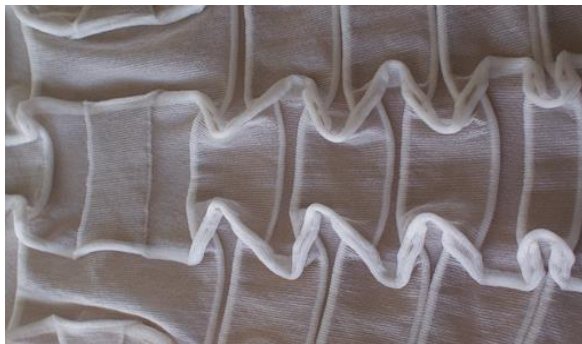
Figure 54: 3D structure (Yun, 2014).

Figure 55: 3D structure (Yun, 2014).

These samples use monofilament as a main material, but include copper composite in the rows where stitch architecture causes 3D shaping to occur. This allows the copper supply to not be used up so quickly, while still showing the most dynamic 3D structures.

Figure 52 is knitted with UV reactive yarn that can be isolated and selectively illuminated with UV light to show the 3D structural shaping in the dark.

Figure 55 is designed in the same way but with a composite of retro-reflective yarn and copper. Retro reflective appears grey in daylight or bright silver-white if the light is directly behind the viewer. Copper and monofilament are especially beautiful in direct light. The strong light makes the fabric seem delicate and elegant, and the shadow can capture the whole structure on the wall or the floor. This projected shadow aesthetic can be created with strong LED spotlights in the dark.

4.2 Lighting and Electronics

4.2.1 Light Testing in the Dark

Figure 56: Monofilament with composite copper surrounding blue neon (Yun, 2014).

Throughout this project, and especially as I produced textiles, I examined and contemplated them in sunlight, shade and florescent lighting – especially in my studio (see Figure 69). Electronic light testing was more contained and specific in set up; mostly conducted in my home garage.

I tested a range of lights to potentially use including standard 25 Watt (W) florescent, 35W halogen and 100W incandescent bulbs. These turned out to be quite fragile, and incandescent and halogen can also be too hot. I also tested EL wire (Electroluminescent wire), neon, and a range of LED (Light Emitting Diode).

Neon illuminates the monofilament effectively but tends to 'down out' the copper (Figure 56). Electroluminescent wire is fascinating due to the thin but consistent light emitted even over long lengths. I have also tested a wide range of LED lights including high power 10W, micro SMD (Surface Mounted Device), UV (Ultraviolet) and RGB (Red, Green, and Blue). Electroluminescent wire and low power LED lights are ideal for use with fabric because they stay cool. High power LED can be adequately cooled with heat sinks.
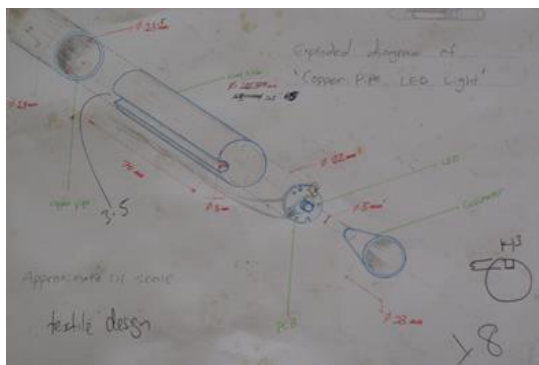
Figure 57: Exploded light design diagram showing heat sink second from left, for AUT engineering department (Yun, 2014).

Figure 58: Actual prototype light showing aluminium heat sink second from left (Yun, 2014).

The AUT Engineering Department has helped me with heat sinks. Initially an engineering technician was interested in my copper wire knitting. After this contact I was able to request his assistance in shaping aluminium rods to use as heat sinks. It was also useful to have the assistance of the AUT 3D lab where technicians helped me bend copper piping into a 'Copper Pipe Lamp-Post' when I was investigating light frame and support options (as shown in Figure 63).

This shows that having the facilities and assistance to selectively extend the scope of a project across disciplines also aids potential innovation. It is asserted in this exegesis that learning the technical skills to produce the object being designed leads to greater potential design innovation. This could apply equally well to lamp design and metal lathes as it does to knit design and knitting machines. Therefore – acknowledging my lack of engineering skills and the limits of this project – the copper lamp design was kept as simple as possible and was constructed to the technician's specifications (square wire channel on heat sink) and not those in my diagram (round wire channel).

The integration of fibre optic strands within the knit textile structure offers exciting possibilities for lighting up fabric from within. A moderately bright 3 Watt LED light focused into one end of a bundle of fibre optics can be seen shining through the other end in average room light. In the dark fibre optics display 3W much more effectively. I have found that scratching – or rather 'nicking' with hundreds of gentle scissor squeezes – allows light to escape over the length of the fibre optic strand. In the dark, this can be used to illuminate a textile structure evenly and effectively.

4.2.2 The Arduino Uno

The Arduino Uno is an electronic micro-controller: basically a tiny computer chip with input and output circuits (Arduino, n.d.). These inputs can be hooked up to sensors that monitor such things as motion with PIR (Passive Infrared), sound levels and light detection. When the Arduino detects a sense signal, it can be programmed to do something with an output.

I am working almost exclusively with light outputs but there is still a lot of flexibility in programming light sequences. Lights can be made to turn on, flash, dim, intensify and turn off. RGB LED can be made to produce primary and secondary colours with additive mixing. Another output that may be investigated before the exhibition is the activation of small fans. Fans may be required to keep the more powerful LED cool, but

the final pieces may otherwise benefit from subtle air movement to introduce a gentle but dynamic element into the exhibition.
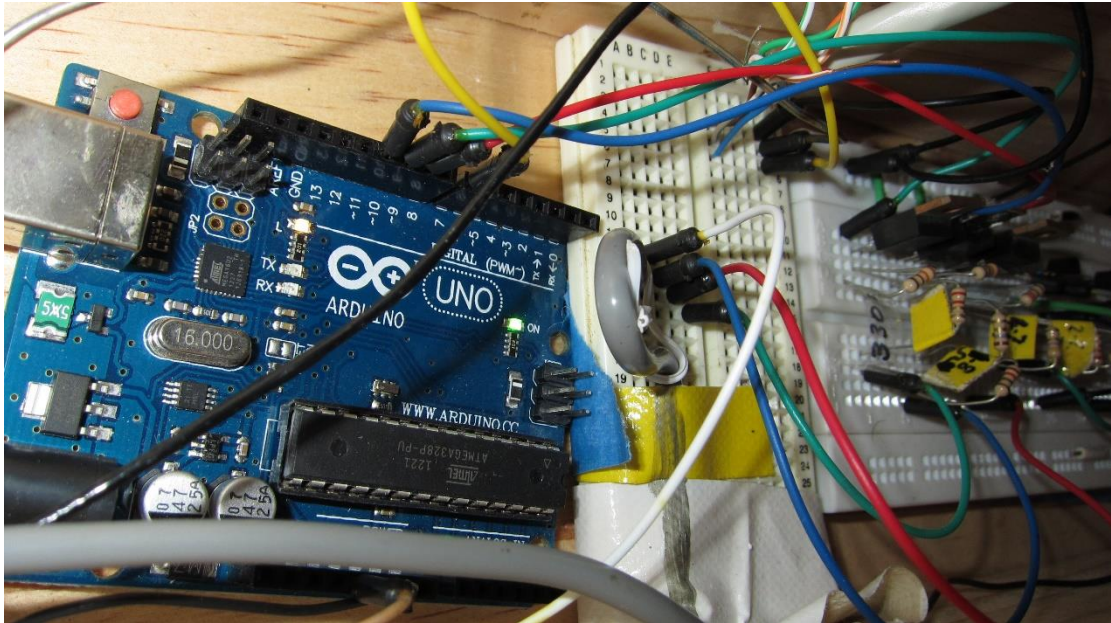
Figure 59: Arduino Uno micro-controller wired to a responsive RGB LED circuit (Yun, 2014).

Using an Arduino allows the integration of adaptive and responsive electronics with the textile sculptures to create 'e-textiles'. Equipped with PIR sensors, the textiles will be able to detect the presence of humans though their body heat, and in response this will trigger a programmed sequence of light adaptations. Experiments with the Arduino and small LED provide a model for larger scale incorporation.
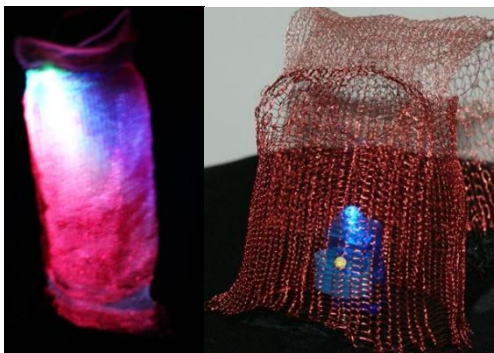
Figure 60: Experiments with copper wire composite textile where the copper in the fabric itself was used to conduct electricity to small LED (Yun, 2014).

By incorporating responsive electronics, I hope to encourage people to look closer at the textiles with greater interest. The changing light conditions will highlight different aspects of the textiles. Bright light throws shadows on the wall and accentuates the internal fabric structure. Dim light softens a fabric silhouette and the textile may seem to glow. I will be very interested to learn how people are affected by and respond to these changing light sequences.

4.3 Final Pieces

4.3.1 Why Does the Moon Follow Me
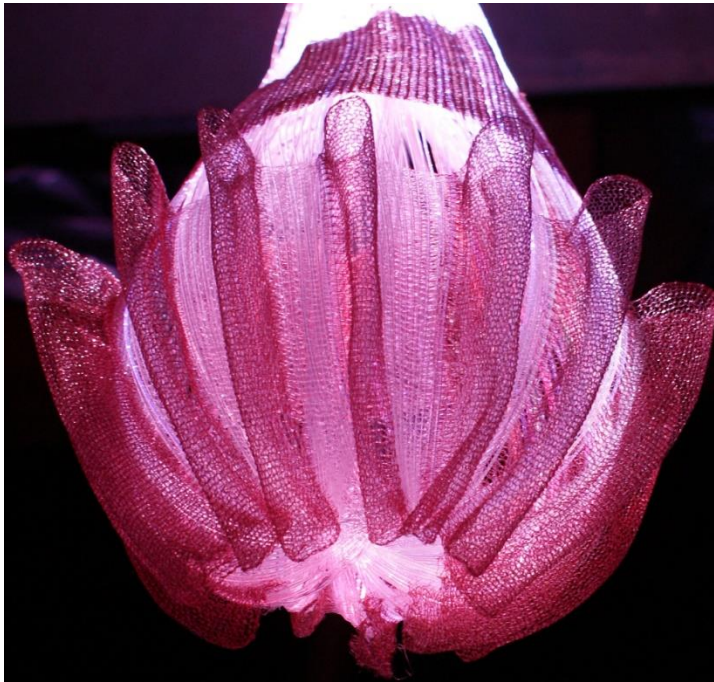
Figure 61: 'Why Does the Moon Follow Me' prototype design sample, with red illumination (Yun, 2014).
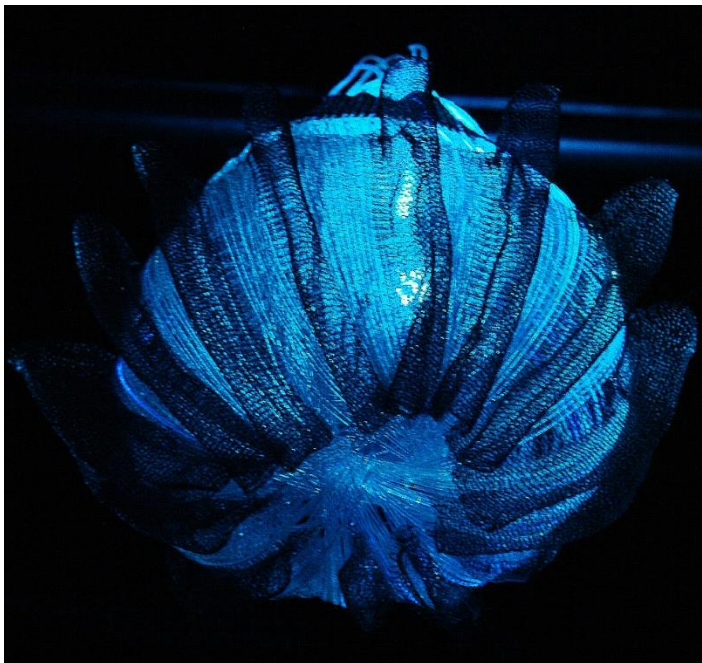
Figure 62: 'Why Does the Moon Follow Me' prototype design sample, with blue illumination (Yun, 2014).

This piece represents my childhood mystification with the moon. As a child growing up in rural Korea I would have to walk long distances. When I had to walk at night the moon would appear to float alongside wherever I went. This made me feel both comforted and paranoid.

These images (Figure 61 and Figure 62) show a prototype sample of the final design. The monofilament and copper 3D ripple knit is interlaid with fibre optics and illuminated with a colour changeable RGB LED.

4.3.2 Beam of Apollo

The initial inspiration for this concept came from the segmented bark on a nikau palm trees, but the Greek god of light and sheep may have been an influence too.

This piece shows the prototype design sample for the 'Beam of Apollo' final piece concept. It is lit with an RGB on full mix which the camera has captured as mostly combining to white.

The final piece is envisioned as being taller with varied 3D folds and darker copper bands. Illumination will come from a very strong LED spot light mounted above the piece to throw shadows on the floor.

The textile in Figure 63 is a continuous monofilament knit, with stripes of copper banded across the ridges of the 3D folding texture.

Figure 63: 'Sample proof' prototype for "Beam of Apollo" conception. Also shows 'Copper Pipe Lamp-Post' than an AUT 3D lab technician helped bend (Yun, 2014).

4.3.3 Translucent Stage
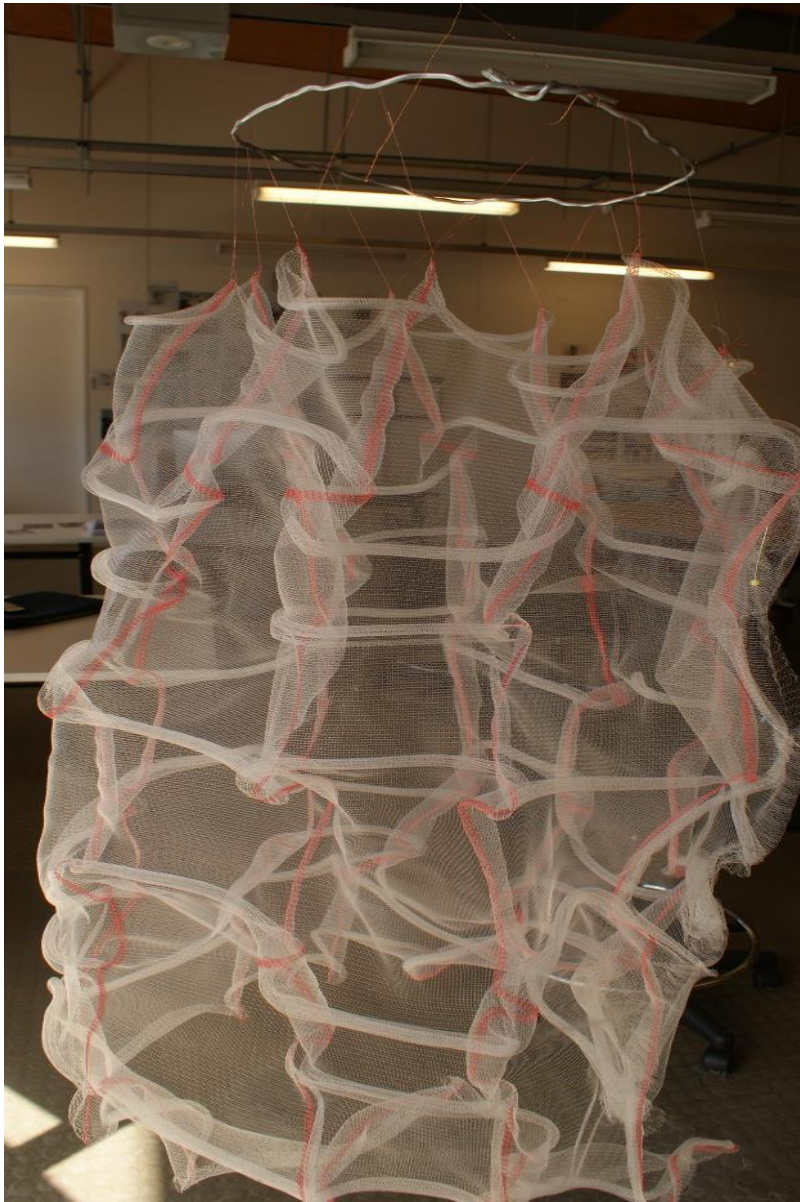
Figure 64: Prototype design towards 'Translucent Stage' with 3D surface shaped monofilament and copper (Yun, 2014).

The intention for this final piece is of a curtain-like shaped monofilament with copper and retro-reflective highlights, spot lit in the middle to project textural shadows against the wall. When viewed from the angle of the spot light, the retro-reflective knit will light up with an intense shine. Also from that position, the viewers' shadow will simultaneously be projected onto the textile piece like a shadow theatre stage.

The prototype example in Figure 64 does not have retro-reflective yarn, but demonstrates the 3D surface shaping that is intended for the final piece.

4.3.4 Ripples on a Wave

Figure 65: Sample proof prototype for "Ripples on a Wave" showing the fibre optic interlay method (Yun, 2014).

Figure 65 is a prototype design showing the effect of RGB LED through 'scratched' side illuminating fibre optic strands that have been interlaid into copper and monofilament double knit fabric. Note this prototype does not show the 3D ripple shaped technique.

The final 'Ripples on a Wave' piece is intended to hang close to the wall and extend in a series of undulating waves. These curves will be made with composite monofilament and copper, regularly interspersed with vertical tubes constructed using the 3D form 'ripple' technique. At one end of the piece the textile will curl into a wide and multi-layered spiral that comes off the wall and is suspended on fibre optic strands. The fibre optic strands will also serve to illuminate the textile spiral. The layers of the spiral will show criss-crossing textures as the knit fabric overlaps.

Chapter 5

5.1 Conclusion

Four finished sculptured textile pieces with integrated lights will form the final Masters Exhibition. Through conceptualisation, development and refinement, the prototype samples shown in this exegesis have demonstrated the necessary design requirements to respond favourably to the research question.

The research question that links this project together is: How can I design and construct innovative textile sculptures made from 3D knitted composite materials, and then exhibit them in a way that expresses their unique material, structural and textural qualities through integration with light.

The '3D knitted composite material' aspect is best represented by a unique combination technique textile produced on the hand-flat. It consists of 3D form ripples made with copper and monofilament composite, interlaid with fibre optic strands. This textile has specialised structural and material qualities in that the knit fabric can be shaped on the fibre optic framework, and the fibre optic strands can illuminate the surrounding fabric. The ripples can be created in small or large rolls to give 3D shapes of varied contours.

A separate branch of research investigated the 3D folding surface technique. This technique was first produced on the hand-flat, then successfully replicated on the Shima Seiki. Research then continued quickly, developing into a range of 3D folding textile designs with varied ratios and composite knit materials.

A prototype e-textile has been created by incorporating motion sensors and LED into a composite knit textile by taking advantage of the conductive nature of copper and the insulative nature of monofilament. Wider prototype testing was carried out with a range of electronic lights to find ways of expressing the translucence of the monofilament, the metallic gleam of the copper, and the high visibility of retro-reflective under specific conditions.

An area for future research would be investigating the sustainability and durability of composite copper and monofilament outside in the elements of sun, wind and rain. I believe this to be entirely feasible as the copper is already enamelled in a sheath of

microscopic polymer, and UV resistant monofilament, such as that in specialty fishing line this can already be sourced.

New combinations of composite yarn and materials are also motivating to envisage. Photochromatic yarns that change colour depending on the temperature or light could make unique sculptures that exhibit differently depending on the conditions of the day, and sparkle at night with interlaid optical fibre. The findings of this research suggest that other strand materials can be interlaid as a substitute or in combination with fibre optic. Research into interlaying strands of shape-memory alloy or 'muscle wire' could potentially add dynamic adaptation in curtains that open with the heat of the sunlight, or furniture that moulds in response to body heat.

The application of 3D shaped composite knitting towards architectural design could be researched along a similar trajectory and methodology as this project. A potential result could manifest as a large scale atrium sculpture where daylight would illuminate the suspended structure. At night such a structure could become the illumination, with the addition of light emerging from within the textile, or through reflecting ambient light.

From a personal perspective, I feel satisfied with the project accomplishments, and gratified that learning to use the Shima Seiki system empowered me to innovate creatively with computerised machine knitting. Knit design innovation can be seen as the combination of new and existing knowledge, the incorporation of imagination and creativity, and a familiarity with technical equipment. In this sense I can corroborate the literature review finding that bridging the gap between design and technical knowledge promotes design innovation.

In conclusion this research presents the formulation of copper and monofilament 3D form ripples in conjunction with interlaid strands as an innovative example of the creative possibilities when combining composite materials with the extension of 3D form techniques. The findings have been provided in such a way as to assist others to replicate and build on this growing area of research.

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Appendix

5.1.1 Studio

The studio photographs show work progress from beginning to later work stages. The displays on the wall, rack and celling were very useful to evaluate the works, and when discussing them with others they could see the physical objects.

Figure 66: Beginning of project (Yun, 2014).

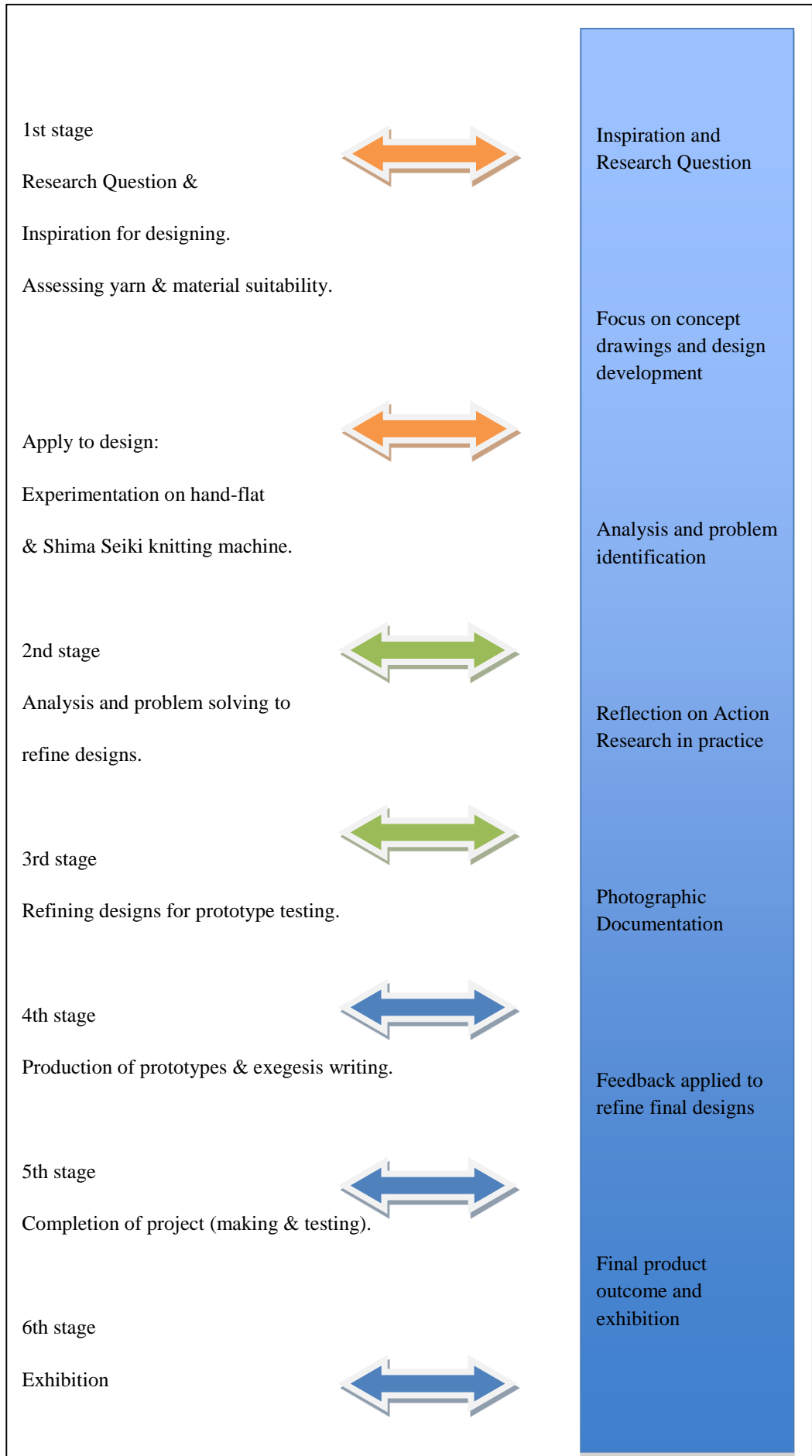*Figure 67:* Mid stage of project (Yun, 2014).

Figure 68: Mid to later stages of research (Yun, 2014).

Figure 69: Towards the end of research, showing prototype textile samples to the fore (Yun, 2014).

5.1.2 Timeline

1st stage

Research Question &

Inspiration for designing.

Assessing yarn & material suitability.

Inspiration and Research Question

Focus on concept drawings and design development

Apply to design:

Experimentation on hand-flat

& Shima Seiki knitting machine.

Analysis and problem identification

2nd stage

Analysis and problem solving to

refine designs.

Reflection on Action Research in practice

3rd stage

Refining designs for prototype testing.

Photographic Documentation

4th stage

Production of prototypes & exegesis writing.

Feedback applied to refine final designs

5th stage

Completion of project (making & testing).

Final product outcome and exhibition

6th stage

Exhibition

5.1.3 Materials

Copper wire: from the left 0.3mm, 0.05mm and 0.12mm. 0.3mm can knit on 3 gauge hand-flat but 0.05mm was too weak to be knittable. 0.10mm ~ 0.15mm was the easiest copper to knit on both hand-flat and Shima Seiki. Copper conducts electricity very well, has a deep and shiny metallic colour and is coated in an enammal so it will not tarnish.

These colourful and different type of yarns are used for experiments on making fabrics that test knit for durable, weight, elastic and quality of each type of yarns.

Monofilament is a kind of nylon. 0.12mm is opaque, strong enough to knit alone and supportive of copper and other fragile yarns when knitted together.
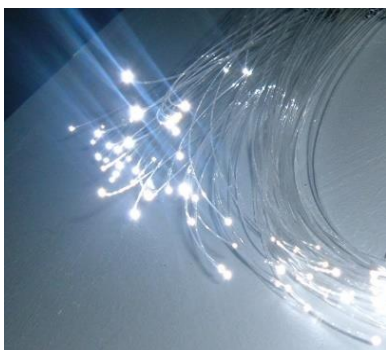
0.75mm, 0.9mm and 1mm fibre optics perform similarly when interlaid between double knit stitches. 0.75mm seems more flexible to bend and shape. Even when fiber optic is interwoven into knitted fabric it does not stop light transmitting from end to end.

Retro-reflective yarn bounces light straight back towards its source. It must be knitted with a stronger yarn to prevent snapping.

Figure 70: Pictures from the top: copper wire, a variety of different types of yarns, monofilament, fibre optic and retro reflective yarn (Yun, 2014).

5.1.4 Knitting Machines Used During Research

The majority of the practical research was conducted on the following two machines.

Figure 71: Shima Seiki SES122-S, 8 gauge (Yun, 2014).

Figure 72: Dubied hand-flat knitting machine, 8 gauge (Yun, 2014).

Experiments were also carried out on the AUT TDL Shima Seiki WHOLEGARMENT®
Knitting machine, a Passap Duo 80 domestic knitting machine, and a Brother KH 830
domestic knitting machine.

5.1.5 Knit-Paint Programing the Shima Seiki SES122-1

When I was taught this program at undergraduate level I had no manual or hand outs so all I had were hand written notes. I began to study this machine and experiment with Knit-Paint. Sometimes I would ask the equipment technician, Rodger Colby, how to knit cast-on, open tubular, bind-off, economise unit, and so on. Then I discovered I could look up the pattern library and copy the stitches to Knit-Paint, or fabricate and reverse engineer the stitches. The more I practiced, the more I understood about knit
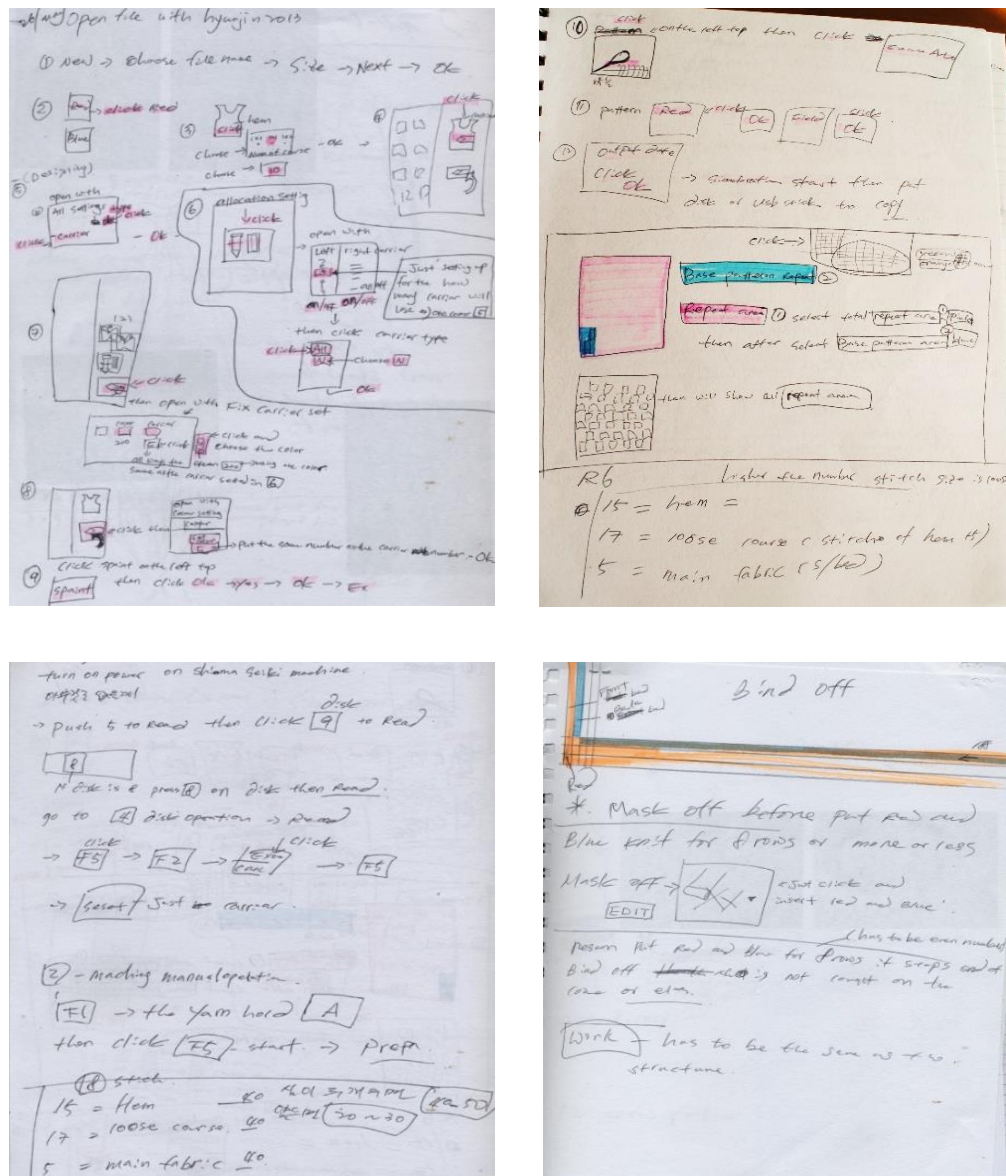

Figure 73: Notes for the Shima Seiki SES122-S 'Knit Paint' software system (Yun, 2014).

architecture, and the more confident I became at adapting hand-flat knowledge to Shima Seiki's Knit-Paint design. Here are notes I kept to understand the programing and remember the process.

5.1.6 Knitting Notation Templates

This knitting chart template system was developed to translate designs between hand-flat and computerised knitting systems. It also helped me record results and keep track of progress easily. All the basic technical information needed to knit is on the chart so it was also possible to use it to communicate with technicians as well. When matched with photos of the resulting knit sample or an actual swatch sample, it was very useful to see the result for analysis and design development.
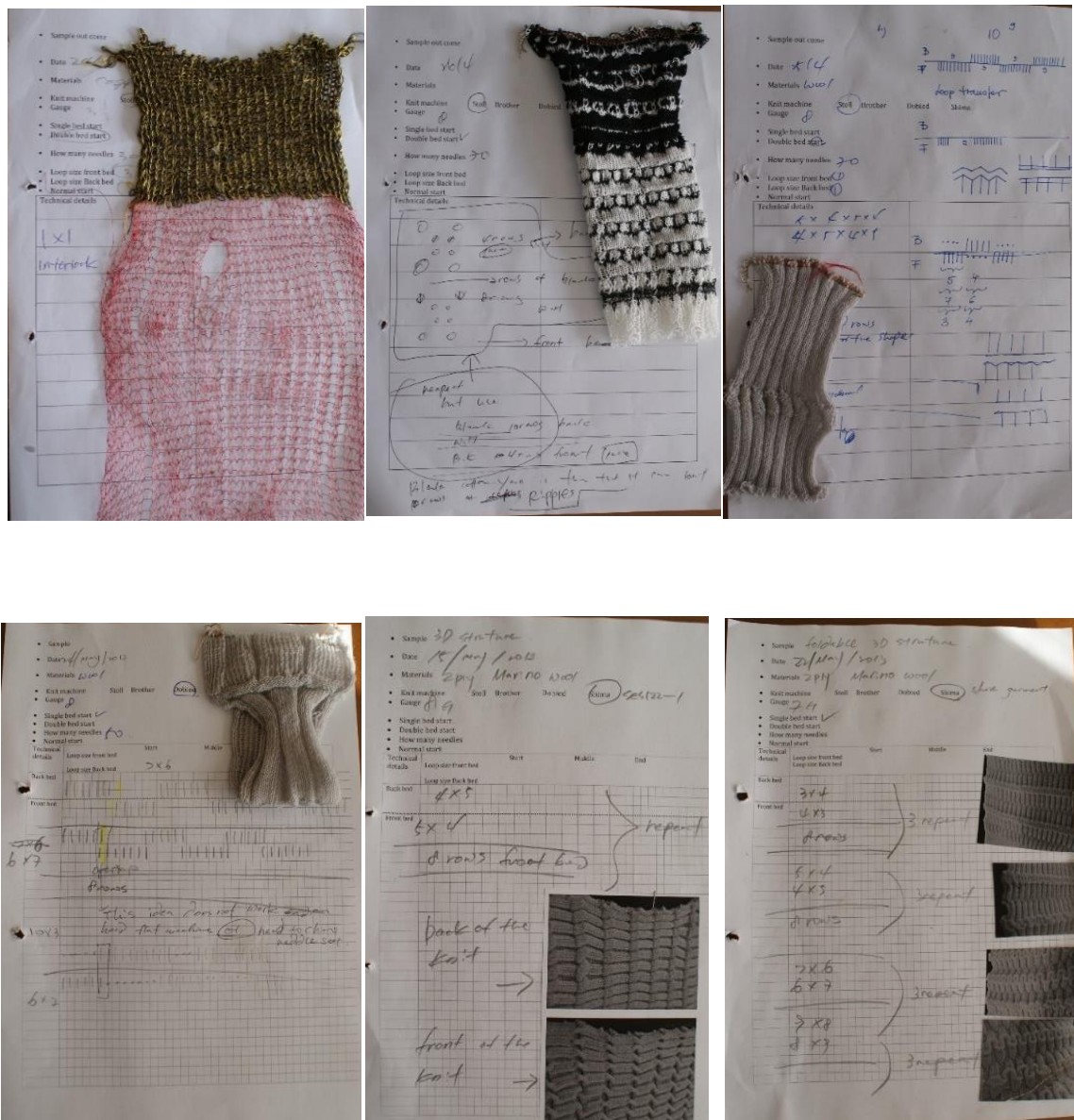

Figure 74: Knit notation charts of knit design documentation (Yun, 2014).

5.1.7 3D Structure Development

I started research by making paper models to visualise 3D structures.

Figure 75: Paper model (Yun, 2014).

Figure 76: Shaping knitted fabric to paper model example (Yun, 2014).

Figure 77: Knit fabric based on the paper model (Yun, 2014).

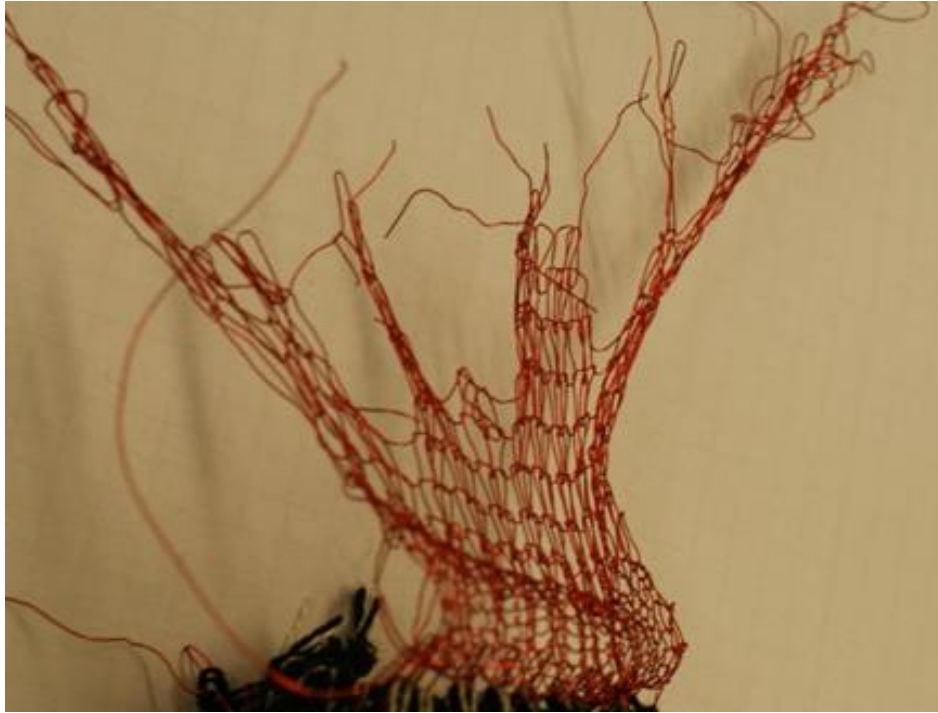## 5.1.8 Problems Knitting Copper

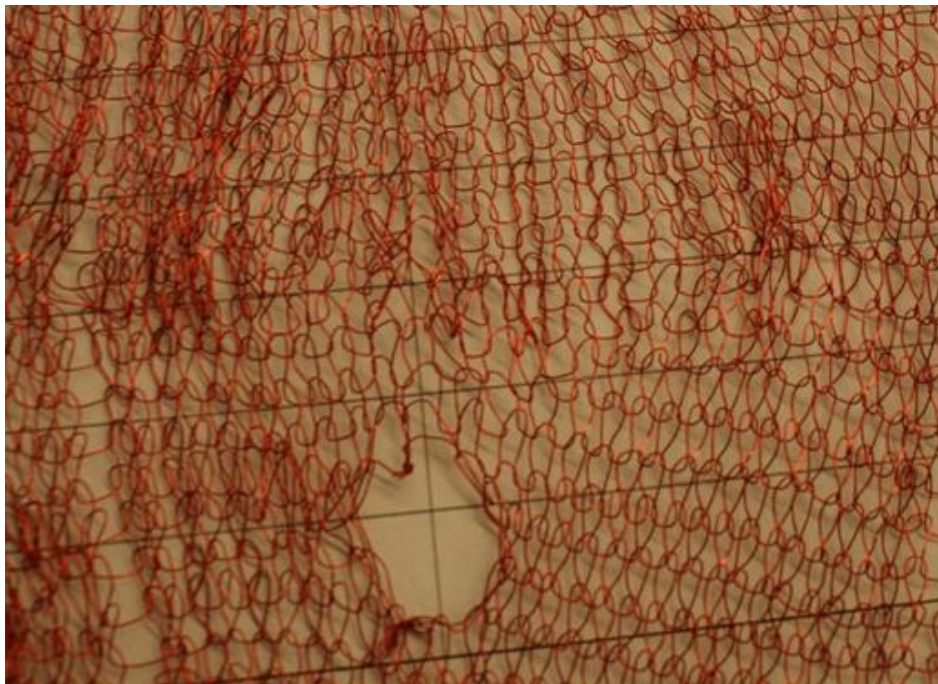*Figure 78:* Copper knitted alone often snaps (Yun, 2014)

Figure 79: Copper knitted alone is also more likely to get runs and ladders (Yun, 2014).

Copper is not elastic or flexible enough to knit alone on knitting machines. To prevent breakage I added monofilament to knit with. This way copper is more likely went through yarn feeder to knit needles.

5.1.9 One Unit of Knitted 3D Folding Surface

This explanation of how to perform 'loop transfer' structure matches the knit notation chart in Figure 80. This explains one unit of the pattern, which repeats.

1. Start with 1×1 rib knit for 4 rows
2. Transfer 14 needles to the back bed and leave 12 needles at the front bed. Knit 12 rows
3. Transfer all needles from the front bed to the back bed and knit 8 rows
4. Transfer 12 needles to the front bed and leave 14 needles at the back bed and knit 12 rows
5. Transfer all needles from the back bed to the front bed and knit 8 rows

Different 3D strutures can be achived by changing the ratio. All begin with "Start 1×1 rib knit for 4 rows" and then the following codes can be swapped in for the codes in the instructions above.

The following ratios have proven to create 3D form surface patterns. Small stitches are (4×5, 12, 8, 5×4, 12, 8), (6×7, 12, 8, 7×6, 12, 8), (8×9, 12, 8, 9×8, 12, 8) etc…… Bigger stitches are (40×50, 40, 16, 50×40, 40, 16), (60×70, 60, 18, 70×60, 60, 18), (80×90, 60, 20 90×80, 60, 20) etc……

Figure 80: Knit notation template with foldable knit structure pattern (left) and sample of this fabric (right) (Yun, 2014).

5.1.10 Measuring the Auxetic Range of 3D Folding Surface Samples

Figure 81: Monofilament and 'metal sparkle' acrylic 3D folding surface fabric. Unstretched left, Stretched right (Yun, 2014).
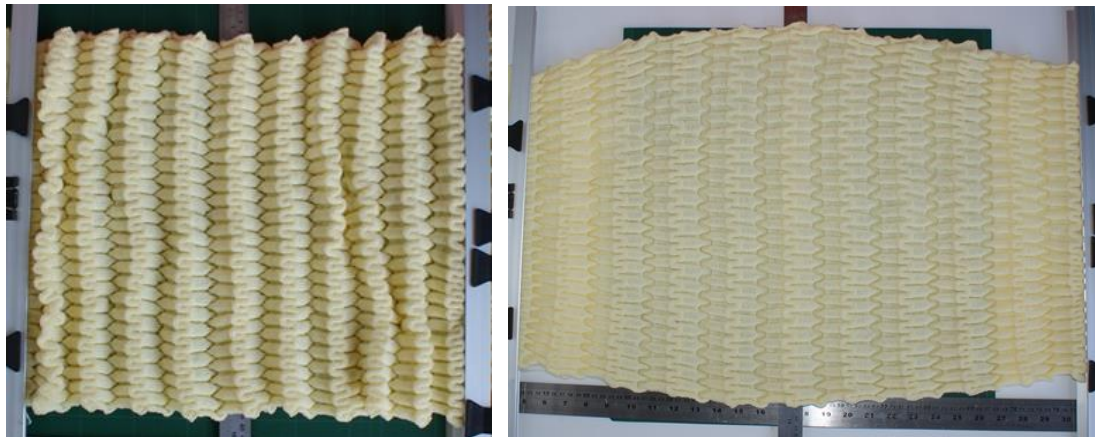

Figure 82: Woollen 3D folding surface fabric. Unstretched left, Stretched right (Yun, 2014).
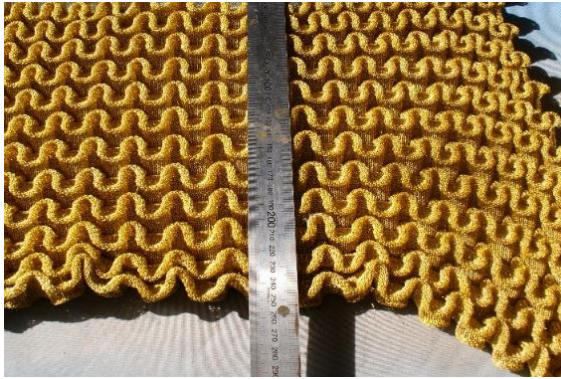
5.1.11 Performance Testing 3D Folding Knit Textile

Figure 83: Composite monofilament and 'metallic sparkle' acrylic prior to heat tests (Yun, 2014).
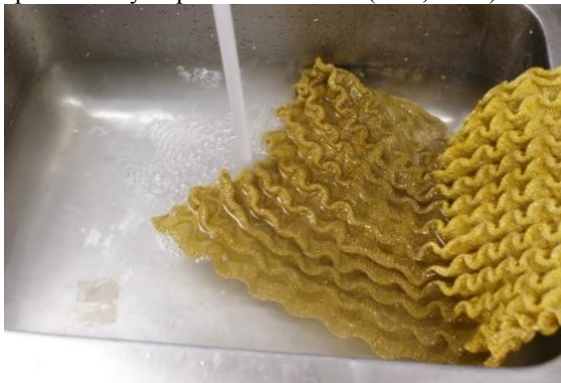

Figure 84: Hot water test (Yun, 2014).

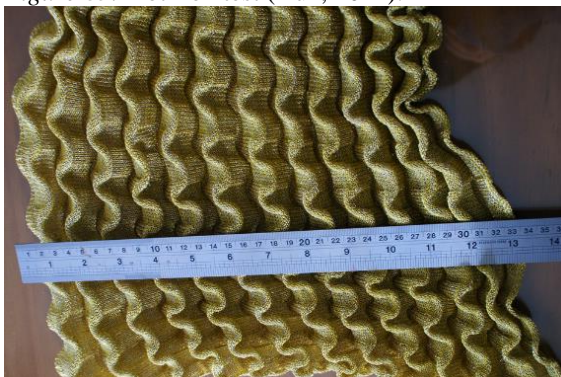

Figure 85: Hot iron test (Yun, 2014).

Figure 86: Measurement after iron test (Yun, 2014).

These experiments test how durable the 3D folding surface texture is. This fabric is a composite of monofilament and an acrylic metallic sparkle yarn.

The first test investigated whether the fabric folds would shrink, flatten out or otherwise be effected by washing with 78 degree hot water. When dry the 3D folding surface textile showed no difference in width or fold height at all.

The same fabric was then ironed at highest temperature over 100 degrees on both sides to measuring how much this would effect it. When the fabric cooled it regained much of the fold shape. It went from initially being 25cm wide at rest, to 30 cm wide at rest after it was ironed. The fabric stretched flat is about 55 cm wide.

This shows there is the potential for very durable shaping. Further tests are needed to determine how the variables material, pattern and temperature relate to the results.

5.1.12 Folding, Unfolding and Shaping

This folding and unfolding seamless knitted fabric was developed like the 3D folding surface textiles on the Shima Seiki WG machine. The collapsible, 'fold-flat' performance shows similarities to Eassy Miyaki's IN-EI range of lights and some of his tubular knit garments.

Figure 87: Foldable and seamless knitted wool fabric (Yun, 2014).
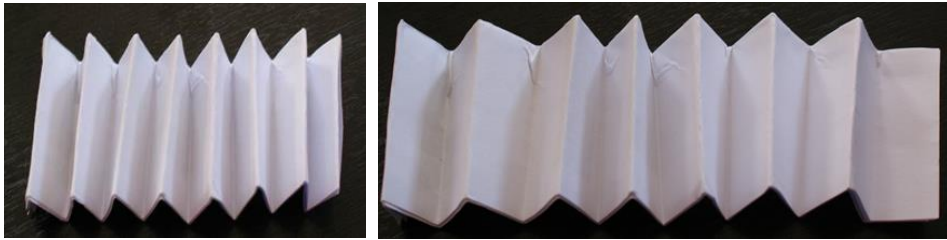
5.1.13 Sideways Folding 3D Surface Knit

Figure 88: Paper model for side foldable knit (Yun, 2014).

This experiment investigated turning the design of the 3D folding surface knit textile 90 degrees (not the knit method – this is still weft knit) to see how the folds would appear to be positioned vertically.

Figure 89: Side foldable knit (Yun, 2014).

Figure 90: Side foldable knit. Self-supported shape (Yun, 2014).

5.1.14 3D Shaped Socks on a Domestic Machine:

This pair of sock was 3D seamlessly knitted on a domestic Passap Duo 80 knitting machine. The 3D aspect is evident in the toe and heal shaping. This experiment took place while learning how to use the SES122-S to understand how hand-flat machines can be used to create 3D shapes. This knit pattern came from an old Passap knitting magazine.

Figure 91: Men's size 8 socks 3D shape knitted on a domestic machine (Yun, 2014)

5.1.15 Experimental New Stitch Techniques.

The question that motivated these experiments was: Can I knit 'open cast-on' tubular on the Shima Seiki SES122-S? This is not true 'open cast-on' tubular. I opened it by cutting the cast-on at the start of knitting.

This technique may potential for extending 3D shaping techniques but further tests are needed.

Also with the SES122-S I tried to knit holes in tubular knit with pitch up and pitch down. It did not work well because when needle transfers yarn from front bed to back bed to create a hole, it drops the back bed stitch.

Then I investigated knitting tubular with stripes on one side only or uneven stripes on both sides. The third from the top picture is a dome shapes of 3D form and bottom of picture is stripes that are knit with copper that it stretches and makes stitch 3D form.

Figure 92: From the top: tubular and textured knit, pitch up and down knit, dome shape knit and uneven stripes knit (Yun, 2014).

5.1.16 Early Prototype 3D Surface Knit Textiles

Figure 93: Test display of 3D surface knit (UV reactive acrylic and cotton) (Yun, 2014).

Figure 94: Test display. Self-structuring 3D surface knit (wool) (Yun, 2014).

Figure 95: Test displaying (acrylic, cotton and monofilament) (Yun, 2014).

5.1.17 Prototype Textile Display Concepts

Figure 96: 'Dragon' Prototype Display (Yun, 2014).

Figure 97: Bag of Light (Yun, 2014).

Figure 98 'Shell' Prototype Display (Yun, 2014).

5.1.18 UV Electronic Light Testing

These knitted on the Shima Seiki SES122-S in order to combine materials that are reactive to UV light. These were early stage experiments with light related materials.

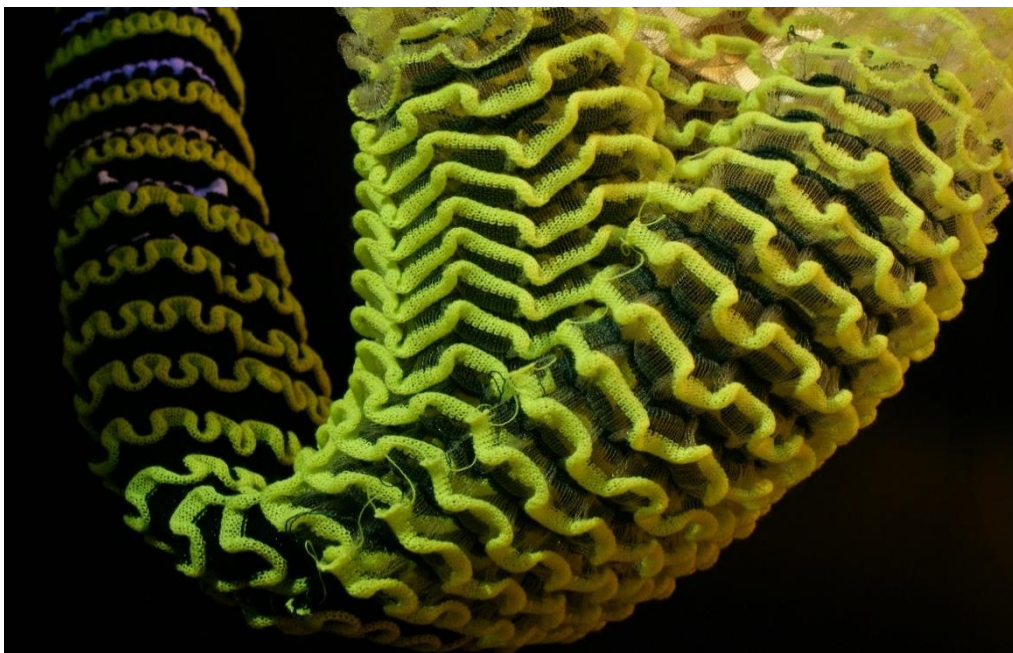*Figure 99:* 3D folding surface made with composite (common) UV reactive acrylic and cotton (Yun, 2014).

Figure 100: 3D folding surface fabric made with composite UV reactive acrylic and cotton, and monofilament in between (Yun, 2014).

5.1.19 Copper Ring Light

Figure 101: Tubular copper ring light (Yun, 2014).

This is a hand flat knitted experiment with a light inside. This work shows that copper wire provides shape and volume in combination with other yarns or alone. The 'rings' that stick out in the picture below are just copper or copper with other yarn, and the concave shaped stripes are just cotton. This tubular fabric was 'stretched out' by hand, the copper rings maintained their shape while the stripes without copper pulled in. The second stripe from the top is a combination of copper, cotton and metallic yarn. This experiment suggests that the non-stretchable and non-malleable nature of metallic yarn prevents the copper from holding a shape as copper alone or copper and cotton.

5.1.20 Setting up lights sculpture

Figure 102: Testing lights sensors and programming light sequences (Robin de Haan).

Figure 103: Testing lights sensors and programming light sequences (Robert Carter).

Figure 104: Setting up halogen spotlights (Steffan de Haan).

Figure 105: Testing up a light pole for a light sculpture (Robin de Haan and Robert Carter).
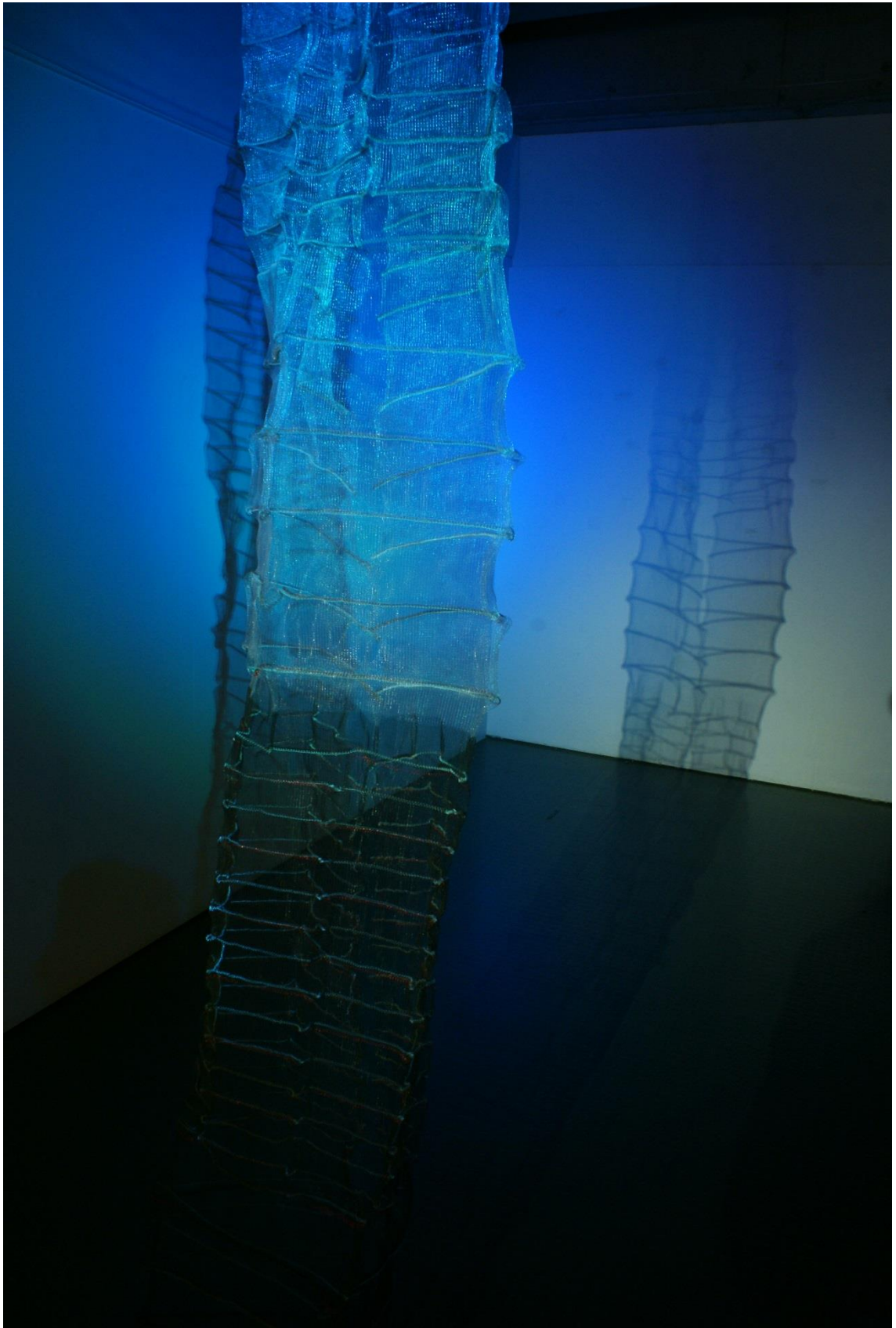
5.1.21 Exhibition

Figure 106: 'Ripples on a Wave'

Figure 107: 'Beam of Apollo' light and shadow

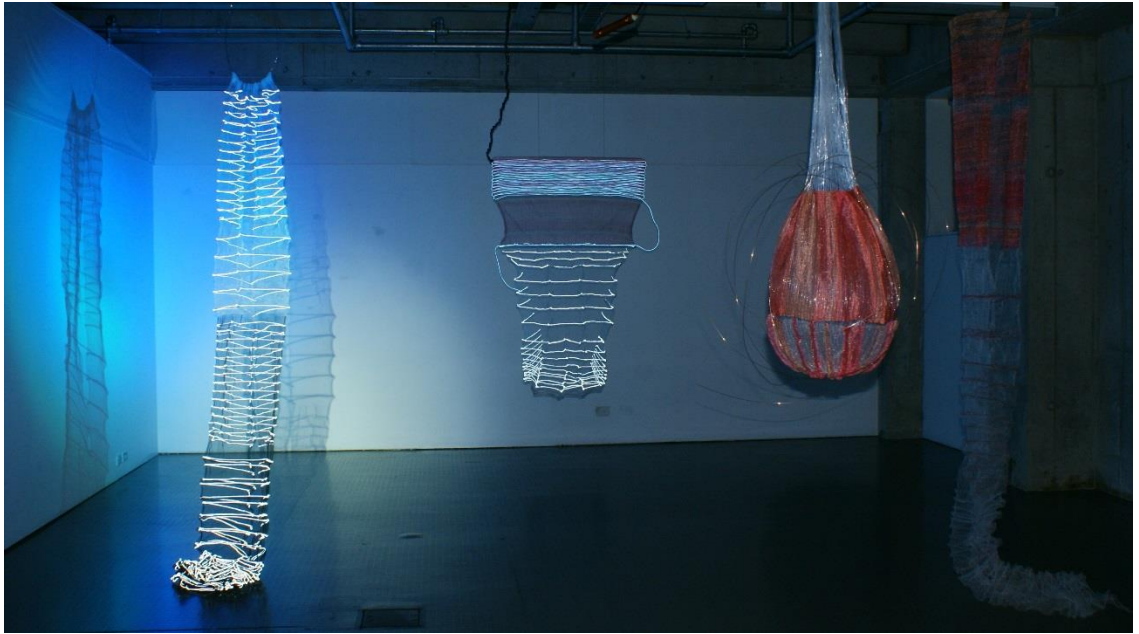*Figure 108:* 'Why Does the Moon Follow Me'

Figure 109: 'Translucent Stage'

Figure 110: E-Textile light sculptures

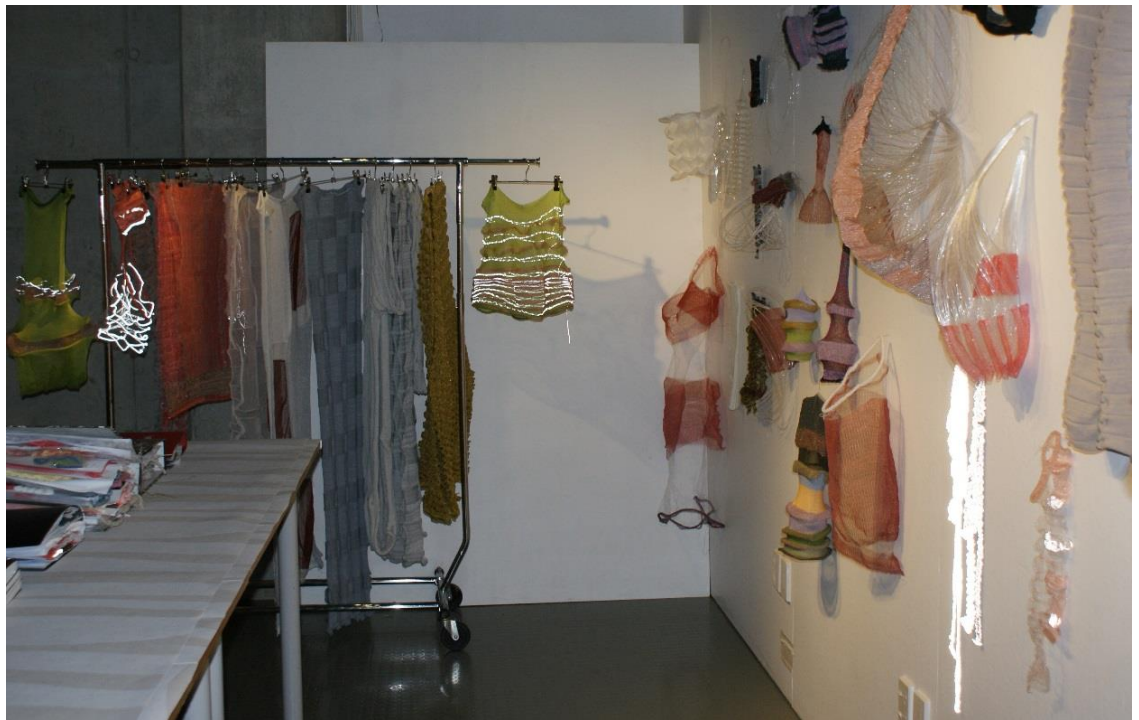*Figure 111:* E- Textile light sculptures

Figure 112: Knitted lights

Figure 113: Knitted lights and fabric