HIERARCHY IN KNITTED FORMS:
ENVIRONMENTALLY RESPONSIVE TEXTILES FOR ARCHITECTURE

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ABSTRACT

This paper describes the theoretical framework behind the development of a series of knitted prototypes inspired by the biomimetic model of the hygromorph. Three moisture responsive pieces are described which use the inherent properties of wood veneer as an actuator incorporated into complex knitted forms constructed from linen and wool. These textile/veneer assemblies are environmentally responsive, transformable and constructed from natural, sustainable materials. This represents a new interpretation of shape changing textiles for architecture. The work illustrates the potential of designing hierarchically organised structures where functionalities are incorporated at different levels of material fabrication. The paper argues that the implementation of textile materials and processes offers the potential for the development of environmentally responsive architecture through the development of shape changing textile/veneer assemblies.

1. INTRODUCTION

The design of shape changing surfaces has developed alongside advances in materials science as a means to explore the potential of smart responsive materials. Shape changing materials can change in shape or dimension, and change back again, in response to external stimuli. Examples include shape memory alloy (SMA), thermal expansion materials, (TEM) and thermobimetals (TB) (Ritter 2007: 46). Both material and form are essential to the dynamic outcome; *Reef* a self-actuated ceiling surface uses minimal energy surfaces to enact dynamic shape changes through the application of electric currents. (Mosse 2011) *Sprout I/O* and *Shutters* explore the potential applications of SMA embedded within a textile substrate (Coelho & Maes 2008).

Biomimicry offers a completely different framework for the exploration of shape changing surfaces. In plants passive actuation can occur in dead tissue simply as a result of differential structuring of the cell wall. In the biomimetic model of the pinecone hygromorph, changes in moisture level are sensed and actuation occurs through differential swelling within the architecture of the cell wall causing the pinecone scales to open and close. It is this biomimetic model in combination with hierarchical structures which inspires this research.

2. RESEARCH CONTEXT

2.1 HIERARCHY

Hierarchy is employed in the design of all biological tissue. Nature relies on a few basic materials, which are combined in an extensive variety of shapes and forms to determine material properties. Hierarchy is important because it allows materials to exhibit exceptional properties and diverse functionality through adapting structure across many different levels from nano- to macro- (Vincent 2008). Specific material properties can therefore be altered without changing every component. By introducing more levels of hierarchy it is possible to make structures more efficient in relation to the material required to achieve certain functionality. (Pawlyn 2011: 42). As organisms grow, this adapted material can be placed exactly where it is required for performance. (Pawlyn 2011: 2).

Wood is a cellular material with a hierarchical structure, which is adaptable across several different levels. As a tree grows, environmental changes can trigger changes in the diameter and shape of the cell cross-section, the thickness of the cell wall or the angle of orientation of the cellulose microfibrils contained within the cell wall. All these adaptations have a major impact on the mechanical properties of wood. Localised variation in structure occurs across all levels of the hierarchy to improve overall performance as required (Fratzl &Weinkamer 2007).

Knitting is a process that embodies at least three different levels of hierarchy: fibre, yarn and fabric. (Eadie & Ghosh 2011) For example the parameter of extensibility can be changed through: (a) fibre; wool is more extensible than flax (linen), (b) yarn; a high twist yarn has more extensibility than a low twist yarn, (c) fabric; a tuck stitch has greater extensibility than a knit or miss stitch. These factors could be altered independently or all together to gain the optimum extensibility for the application.

2.2 BIOMIMETIC MODEL

The aim of the research is to develop fabrics that can change in shape in response to changing environmental conditions without any other control mechanisms or energy. Passive actuation in plants is a useful model for analysis as movement is actuated by environmental changes, controlled by cell structure and does not require further energy supply for actuation. (Fratzl et al 2008) The pinecone hygromorph is an example of this actuation method, whereby the opening and closing of scales on the pine cone occurs after the cone has fallen from the tree. This is caused by differential swelling and shrinking of specific parts of the tissue. Three key areas for investigation have been identified for development into hierarchical knitted textiles: (a) The material is a composite of more than one material one that swells and one that resists swelling which forces the material to distort.

(b) The orientation of the fibre determines movement, either by controlling potential shrinkage or by allowing swelling or shrinking. (c) Deformation within a small area of a scale is amplified through the structure geometrically (Fratzl et al 2008; Martone et al 2010; Vincent et al 1997).

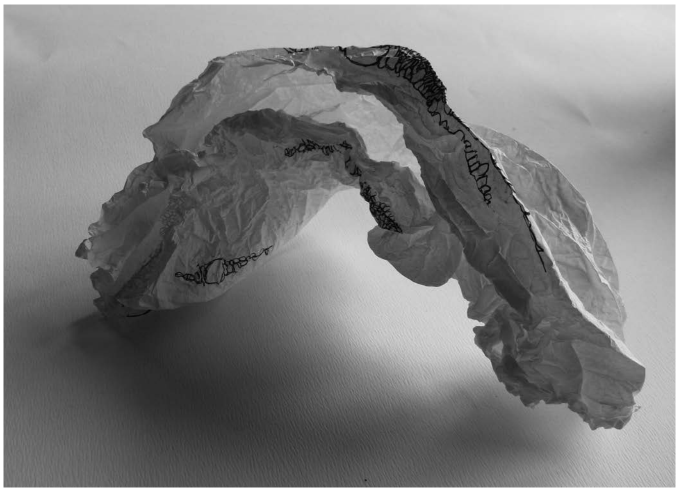
3. IMPLEMENTATION OF HIERARCHY

3.1 FIBRES

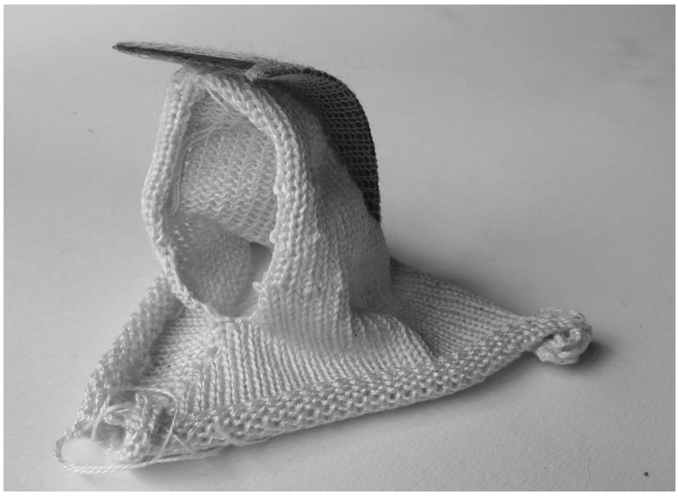
Natural fibres have dynamic moisture absorption properties. It is this quality that allows clothing to absorb moisture from the skin during wear and is fundamental to traditional laundering processes. However, there is potential to develop this characteristic beyond the conventional. Natural fibres swell and increase in volume and density in the presence of water. Changes in size shape stiffness and permeability occur. This has direct impact on the mechanical properties of the yarn and fabric.

Wood, composed of 40-50 per cent cellulose is easily penetrated by water. The mechanical and physical properties of wood are changed through varying levels of water within bound water of the cell walls. (Hon & Shiraishi 2001: 575-77) Wood swells and shrinks in different directions by different amounts. The greatest shrinkage occurs in the tangential direction (8%) water is absorbed most rapidly in the longitudinal direction however the least shrinkage occurs in this direction. (0.1%) (Tsoumis 1991: 146-53). Veneer will bend due to differential expansion in the radial and tangential direction. If water is absorbed through one surface of a veneer it will bend.

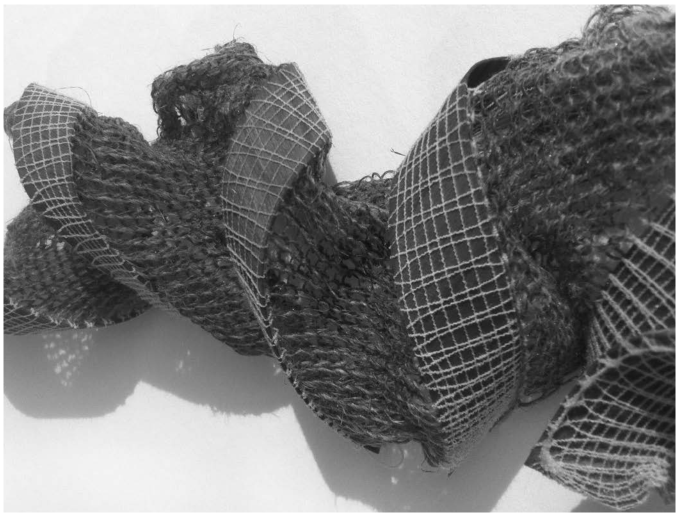
1 Form-finding: natural forms



2 Form-finding: paper crumpling



3 Form-finding: knit processes



4 Form-finding: knit processes

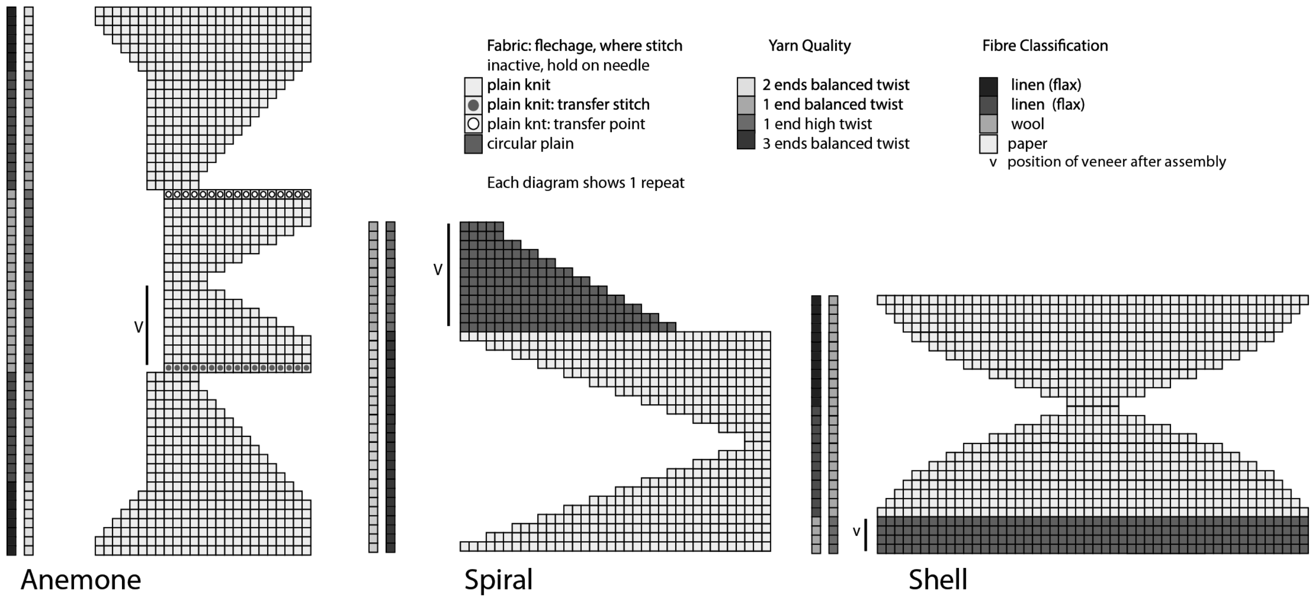
3. 2 YARNS

The orientation of fibres in natural materials imparts many of the mechanical properties of the material. Fibre orientation in textiles is regulated during the spinning process where fibres are aligned and twisted together providing strength and flexibility to the resultant yarn. The yarns used in the development of the knitted assemblies are a combination of singles and folded yarns, which provide contrasting balance within the structure. Overtwist or crepe yarns have also been incorporated in the designs, these yarns shrink by approximately 30 per cent in the presence of water.

3.3 FABRIC

Weft knit fabrics are composed of loops of yarn; it is the interlooping structure that provides the natural morphology and determines many of the fabric properties. The interdependence of each knitted loop with adjoining loops on either side, above and below it produces a versatile, adaptable material. Under tension, weft knitted loops will easily distort; loops are capable of stretching both horizontally along a course and vertically down a wale, as the yarn is free to move to adjacent loops within the structure. This characteristic provides knitted fabrics with exceptional levels of extensibility, deformation, stretch and recovery compared to other textiles (Spencer 2001).

Fabric can be produced as flat shaped pieces or as three-dimensional forms. Manufacture is an additive process; fabric is formed from constituent yarns on a stitch-by-stitch basis along a horizontal course. Fabric shape can be altered by increasing or decreasing the number of stitches knit. Fabric properties can be changed at any point during construction through changes to the fibre, the yarn or the type or quality of stitch used. At this level of the hierarchy, mechanical properties can be altered by manipulating the parameters of loop length and stitch density and through the introduction of three basic stitches, knit, miss and tuck.



5 Technical repeats of knitted fabrics, machine state: Anemone, Spiral, Shell.

4. DESIGN IMPLEMENTATION: HYGROMORPHS

In order to test the biomimetic principles, a series of knitted prototypes have been developed. The hygromorphs are a collection of moisture active knitted forms composed of natural materials that slowly transform in shape from flat two-dimensional surfaces to three-dimensional forms. (Figures 6-11) Inspired by natural forms (Figure 1) and explored through paper based techniques (Figure 2), designs were planned as two-dimensional nets and knitted using a combination of single bed techniques. (Figure 5) Development work was undertaken through sampling on knitting machines. (Figure 3 and 4) The aim of this initial prototype collection was to implement the theoretical framework and illustrate dramatic shape change potential of the technique.

Fabrics were tested in a domestic environment at ambient conditions using a cold-water spray to actuate the structure. Actuation was recorded on video and, where possible, both the actuation and the return to the original state were recorded.

5. ANALYSIS

Analysis is considered with reference to both the hierarchical structure and the biomimetic model. Shape changing occurred through careful manipulation of the different hierarchical levels of fibre, yarn and fabric. (Figure 11) Shape change was programmed into the textiles through a combination of material choice, incorporating biological materials and natural fibres, varying the twist properties of yarn, and selecting various stitch types and fabric forms.

The pieces can be described as assemblies, as they have been constructed from different materials within the same fabric. By combining linen and wool in knitted panels the fabrics maintained both the property of extensibility, in order to deform, and recovery, in order to return the fabric to a relaxed state. Flechage, (a technique of selectively knitting and holding stitches within the same course) determined the three-dimensional form achieved after actuation. Veneer is enclosed within panels of circular plain to provide the means of actuation. (Figure 5) The high twist wool incorporated within the panel of circular plain exhibits good extensibility, and provides resistance to the veneer. (Figure 12) The wool has the advantage of shrinking significantly in contact with moisture, further improving the resistance. Anemone is the most complex form comprising three levels of

6 Shell before actuation, L40cmxW18cmxH3cm

7 Shell after actuation, D18cmxH8cm

construction within a single fabric achieved though flechage and partial knitting. (Figure 12)

In the biomimetic model of the pinecone the fibre orientation determines the movement, within the knitted hygromorphs movement is controlled across all three levels of hierarchy; the fibres within the veneer determine the rate of actuation and the degree of movement of the veneer. However, the overall shape is controlled by both the yarn and the fabric form. By manipulating any of the parameters the outcome is significantly altered. By working across the levels of hierarchy the deformation has been applied geometrically throughout the forms again. In the example of Anemone, the fabric form created through flechage and partial knitting allows individual forms to appear and disappear in the actuated state, whereas in Spiral each veneer segment acts in a uniform manner to control the actuation.

6. CONCLUSIONS

This work explores the potential to design environmentally responsive shape changing knitted assemblies using natural sustainable materials. Whilst prototypes remain at a small scale, the work suggests that simple natural materials are capable of dramatic, dynamic functionality. The work highlights the importance of function in the development of shape changing materials, exploring the potential advantage of designing using structural hierarchies. It questions the traditional field of smart materials, asking whether natural materials with inherent, programmable, shape changing functionality could be considered within the field of smart technologies.

8 Anemone before actuation, D35cmxH0.2cm

9 Anemone after actuation, D35cmxH7cm

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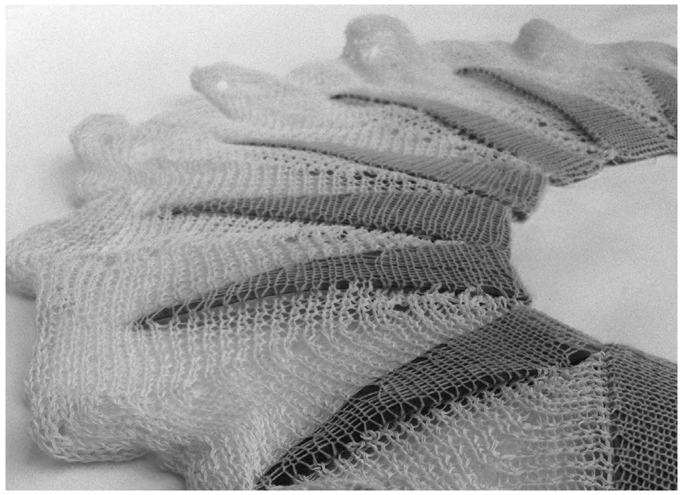
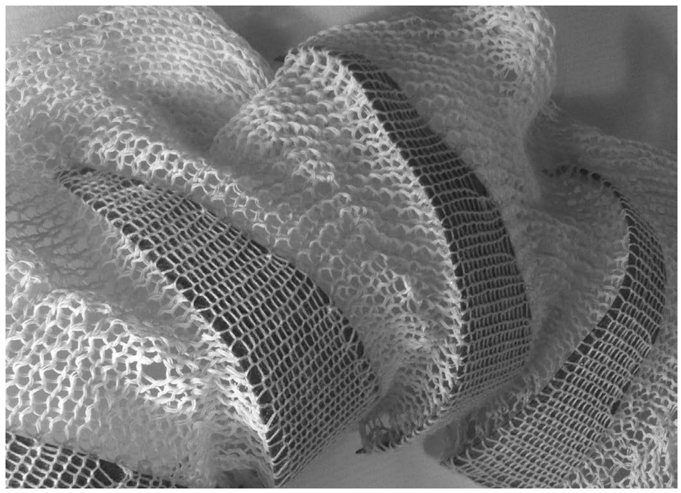


10 Spiral before actuation, D40cmxH 0.1cm



11 Spiral after actuation, D40cmxH4cm

Design	Hierarchies													Observations
	Fibre	Yarn								Fabric				Swelling (SW) Shrinkage (S) Extensibility (X) Resistancee (R) Form Generation (FG) Shaped (SH)
		Count New metric (nm)	No. of ends			Single (S) Plied (P)		Twist: balanced (B) high (H)		Stitch quality	Fabric type Flechage (F) Tubular (T) Stitch Transfer (s)			
			1	2	3	S	P	B	H		F	T	S	
Shell 7gg double bed machine	Flax/ Linen	1/18	x			x		x		10	x			SW,SH,FG 2d-3d
	Wool	2/48	x				x		x	10		x	x	S, R,X, FG
Anemone 6gg single bed machine	Flax/Linen	1/18		x		x		x		5	x			SW,SH,R,FG
		1/18	x			x		x		2	x			SW,SH,FG, Segments rise
	Wool	2/48	x				x		x	0.2	x		x	S, R,X, SH, FG
Spiral 7gg double bed machine	Paper	1/52			x	x		x		8	x			SW,SH,EG, 2d-3d
	Wool	2/28	x				x	x		10		x	x	S,X,R,SH,FG

12 Analysis of design work showing material choices and hierarchies