Nature as paradigm for sustainability in the textile and apparel industry

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The functional profile of clothing is in the midst of reform. A wave of new technology has entered the sector promising properties that could be extracted directly from science fiction. The technical textile industry has already implemented many of these innovations on a commercial scale; smart polymers and gels are used to create textile scaffolds for medical implants, electronic circuitry is woven into garments used in military and surveillance contexts, temperature sensitive pigments are applied to infant clothing to monitor body temperature and prevent cot death. As these technologies move from niche to the mass markets through clothing and fashion applications, the relationship between garment and wearer is redefined as are our expectation of clothing performance.

Already there are several smart products available to consumers: jackets that couple to mobile phones or MP3 players, clothing that can protect the wearer from UV rays, insect bites, microbes, 'self-cleaning' stain resistant garments. With many more innovations in prototype stage the future holds a huge influx of new functionalities that will add to the repertoire of conventional clothing properties. The question on many critics' lips is: do we actually need these new functionalities; is there a consumer pull for this technology push?

There are many factors that contribute to the seamless integration of new technology into existing product groups and what the consumer perceives as useful. The key is that new technology must offer a solution or at least improve on a problem that cannot be solved with conventional methods. If we widen our focus from fashion products on the 'shop floor' to the key issues dominating the clothing sector, opportunities for innovation become apparent. The sustainability of existing practice within the clothing industry is not a new issue. For decades stories of ecological and ethical impact have surfaced and captured media attention, but there is far more public awareness today than as little as five years ago. Can new technology offer solutions that will reduce the negative impact of existing practice? Are there any disruptive new paradigms?

Biomimetics is a term coined by the polymath Otto Schmitt in the 1930's to describe an electronic feedback circuit he designed to function in a way similar to human neural networks, as part of his doctoral thesis. Over the following decades, several synonyms such as *bionic, biomimesis, biomimicry, and biognosis* popped up in various parts of the world to describe developments inspired by the functional aspects of biological structures. A compound word of Greek origin, *bio*- meaning life and -*mimesis* meaning to copy- biomimetics describes the interpolation of natural mechanisms and structures into the man made world.

Biomimetic thinking is by no means novel to the textile sector, it is an ancient relationship that dates as far back as 3000 BC in China and is bound by an obsession with silk fibres that eventually led to the birth of the man-made fibre industry. The only natural fibre found in continuous filament form, silk demonstrated unique lustre and fineness, coupled with high tensile strength. These properties rendered the fibres a precious commodity that remained a carefully guarded secret for millennia, contained within the borders of China. Attempts to produce fibres that imitated the properties of silk were unsuccessful for thousands of years. The first patent for 'Artificial silk' was granted in 1855, it described a cellulose mixture similar to the one eventually used for the successful commercial production of Rayon in 1910.

Rayon imitated the lustre of silk but lacked its strength. In 1938 the first synthetic fibre entered the market whose fineness and strength surpassed that of silk. Nylon by DuPont was quickly hailed the 'miracle fibre' and caused an unprecedented revolution in the clothing and textile industry. The synthetic fibre industry enjoyed a boom epitomized when Neil Armstrong planted a nylon flag on the surface of the moon in 1969 having taken "One small step for man, one giant leap for mankind" in a space suit made from almost 30 textile layers of nylon and aramid fibres.

The 1970's saw a backlash as garments made from synthetic fibres fell from favour while demand for clothing made from natural materials increased. Market saturation and the 1973 energy crisis began to turn consumers away from the 'new' materials. Product advantages such as ultra-fine cheap stockings and quick drying, no-need-to iron clothing were overpowered by the unforeseen drawbacks of the technology which caused a new type of discomfort sensation to wearers. Static electric charge, itchiness and damp, clammy sensations on the skin were all symptoms that tormented wearers. Consumers returned to clothing made from natural fibres for comfort and the synthetic fibre industry turned its attention on producing textiles to imitate the comfort properties of natural fibres.

Biomimetic developments today are the product of collaborative work between biology and engineering. The conceptual link between the two disciplines is based on the use of available resources/ energy. In nature, plants and animals live in competition with each other for access to limited resources. Successful species use clever design and optimal distribution of raw materials to evolve ways of living and reproducing using the least possible resources. This level of design optimization is what attracts engineers to search for paradigms in biology. Nature can offer ideas for developing cleverly designed/ low energy materials and structures mindful of the greater cost to the environment in the construction of man-made products.

If we look at the way materials and structures are formed, sustained and recycled in nature, we have an apparently simple model that can offer some ideas to improve practice in the clothing and apparel industry.

Design in nature

Fibres are the basic building blocks in textiles; production of both natural and man-made fibres relies on high levels of resource such as energy (temperature, pressure), water, the use of toxic chemicals (such as fertilizers and insecticides in the case of natural fibres) to produce grades of fibre suitable for use in textiles for clothing. Resource intensive processes have replaced traditional 'low energy' methods to increase production and reduce cost for example in the case of the processing of flax. Flax fibres were traditionally separated from the stem and leaf by retting in ditches, a low energy process relying on the natural rotting of plant parts. In order to speed this process up and increase productivity, traditional methods have been replaced by chemical and hot water systems (Slater, 2003) and are now widely used in the industry.

There are cases where low energy technologies have replaced traditional methods to reduce the environmental cost of fibre processing. Colonies of enzymes, which thrive in damp yet mild conditions, are now regularly used to clean and prime fibre surfaces for further processing such as dying and finishing. Normally this process requires the use of hot water and harsh chemicals. Enzymes are also used in later stages of fabric finishing, replacing energy intensive processes such as stone and sand-washing of denim jeans.

There are two main types of polymer occurring naturally and over 300 in the man-made arena. Conventional engineering relies on the properties of a material to deliver the desired functionality to a structure. Whenever a new property is desired a novel material is synthesized. In contrast, functionality in natural living systems is achieved using structural variations of either protein (basis of silk and wool) or polysaccharide (basis for cotton, flax etc) (Vincent et al., 2006). Design in nature occurs on the molecular level, structures made from the same polymer can demonstrate great variations in mechanical properties such as stiffness, strength and elasticity as a direct result of the assembly of their polymer chains.

Cellulose (a type of polysaccharide) is an abundant natural polymer and forms the basis of all plant structures. Cotton and flax fibres are both made from cellulose polymers yet their properties are very different. Generally, cotton fibres are weaker more absorbent and resistant to creasing than flax fibres (Cook, 1984), how can this be if they are made from the same material? The functionality of both fibres in their natural state is very different, Flax fibres are extracted from the plant stem; they need to be stiff and strong to provide necessary structural support. Cotton fibres are really a single cell trichome (type of hair) that grow from the seed coat and are designed to enable dissemination in windy conditions at maturity. The key differences in mechanical properties between the two are due to the orientation of the cellulose polymer chains within their cell walls. Stiffness and strength are characteristics engineered by closely packed and aligned polymer chains, while moisture absorbency and elasticity result from less organized *amorphous,* configurations. Although both fibres are made from the same polymer, differences in the way the polymer chains are assembled is a key factor in the definition of the fibre's mechanical properties.

Bionic fashion

'The suit is my shape, extended, but its mind isn't mine; its independent.' (Banks, 1993)

Fashion is unconventional by nature, it is about breaking boundaries and challenging the role of clothing as a means of adornment, a social tool and an artefact. Pioneers of the past such as Coco Chanel who was the first to introduce traditional men's fabrics and tailoring methods into womenswear and Paco Rabane who created clothing from unconventional materials such as paper, plastic and metal combined available state of the art materials with innovative construction methods to design ground breaking fashion that altered the public's perception of what clothing could be.

The technology available to fashion designers today has created a new breed of innovators more akin to engineers. In 2007 Hussein Chalayan applied technology previously confined to engineering laboratories onto the catwalk through collaboration with engineers and technologists from other disciplines Both Autumn/ Winter and Spring/ Summer collections feature garments made from LED textiles that display moving images as well clothing that alters its shape using moving mechanical parts. The impact of 'fashion engineers' such as Chalayan today on fashion consumers of the future may not be that dissimilar to that of the previous century's fashion innovators.

Imagine if clothing of the future would adapt, grow, self repair and change appearance. The relationship between wearer and garment would be that of symbiosis enabled by developments in material science that produce textiles able to imitate functionalities of living organisms rather than just the properties of natural fibres. (Tao, 2001) uses the living cell as a metaphor to describe future textile functionalities and forecasts behaviours such as self-repairs and adaptation. We can expect clothing of the future to host an array of new properties that may interact or integrate with the body, self maintain, reproduce and self assemble to accommodate changes in our activity and environment. Materials and structures in nature already demonstrate these functions and can indicate ways of transferring the technology into clothing. Biomimetics can operate as a platform to accommodate these future requirements and provide a new perspective in the design and assembly of clothing systems.

Cultivating couture

Materials, in nature, are formed using minimal amounts of energy and rely on the resources found in their immediate environment; plants for instance, need nutrients from the soil, sunlight and water. Imagine if we could 'grow' materials. London based researcher Susanne Lee has been investigating methods of growing garments as part of a project titled Biocouture. Lee uses cellulose producing bacteria Acetobacter xylinum to create sheets of material that are cut and made into garments.

Although Lee's manufacturing concepts are in their infancy. If this technology were to mature successfully, we would be looking at garments grown using sustainable sources, minimum energy and no waste. The main scientific and technical challenges evolve around the identification of a controlling mechanism to manage the orientation of the cellulose microfibrils. This potentially would lead to the engineering of 3D garment shapes from a solution

Self-repair

Today's throwaway society, consumers are more likely to replace an item of clothing once it is damaged than repair it. The additional resources necessary for repair (cost, time, skill, and availability of materials) generally do not outweigh perceived benefits over the extension of the item's useful life. One factor is consumer perception of low cost items as perishable/ disposable. Repairs and alterations still occur but are reserved for expensive more 'valuable' items. Another factor is that repair requires an external input of resource that is not always instant, practical or obtainable. Consumers in general lack skills and perceived time necessary to carry out any structural maintenance work and need to seek out necessary expertise.

Self-repair in nature involves the redistribution of internal resources to address damage. The transfer of this concept to a garment system suggests a complex interconnecting textile network able to sense damage and act accordingly, an eventuality reserved for the distant future, or is it? German biologist Dr. Olga Speck[1] of the Biomimetics Competence Network has headed up a project to develop self-healing membranes that disperse repairing foam stored in cells along the surface of the film. A puncture in the membrane locally ruptures the blisters which release the repairing foam that seals the damage. It is possible that developments to this type of technology could be implemented into clothing fibres of the future creating self repairing systems able to extend the useful life of a garment.

Shape change

Clothing may also be able to assume several shapes, tactical or systematic metamorphosis would alter the appearance of garments according to changes in both internal and external requirements. Shape change is an important area for development in terms of sustainability; by altering the physical dimensions of a garment you can manipulate performance, appearance and expand the range of usefulness. A single item of clothing could be suitable in one state for a professional working environment such as an office, and then in its alternative state it can fit into a social/ leisure environment carefully designed alterations in volume and coverage of the wearer's body would be sufficient to realise relevant changes in functionality.

Complex mechanical substructures have been used to alter the shape of catwalk showpieces by pioneering designer Hussein Chalayan, however

[1] US patent application US 2009/0035551 A1

shape memory alloys allow a more ‘seamless’ integration between technology and clothing system. It is possible to spin smart alloys into fibres suitable for use in garments, in June 2001 Grade Zero Espace (a Copro Novo spin off company) successfully incorporated an alloy called Nitinol into a woven textile branded Oricalco, a prototype shirt was manufactured using this textile that is able to shorten its sleeves if the environmental temperature rises above a certain predetermined point. However, the cost of the basic raw material Nitinol prohibited the commercial production of Oricalco, the production of the shirt prototype was estimated $3500. Prototype ranges created by fashion engineers such as XS Lab and Cute Circuit use Nitinol in much smaller quantities.

Visual display

Colour and pattern change is a vital survival mechanism for some animals for protection and communication. Chameleons are iconic creatures known for their ability to mimic the colours and patterns of their surroundings and become ‘invisible’. Cephalopods (octopus are part of this group) also use the surface of their skin to create highly complex visual displays for protection, communication and to intimidate predators. Enabled by a highly sophisticated mechanism, that actively engages combinations of pigment and structural coloration, scientist have been most fascinated by the fact that the visual display is controlled by the animal’s nervous system and hormones. Following an intensive programme studying the way cephalopods alter areas of their skin structure to manipulate the light reflected. In 2007, a team lead by Professor E. Thomas of Massachusetts Institute of Technology (MIT) developed a smart gel able to alter its colour in response to environmental stimuli such as moisture, temperature and PH.

Although this technology is in its infancy, several approaches are being explored that promise to deliver colour changing clothing in the future. The benefits echo those of shape change, extended range of use and ability to adapt to social surroundings. An eventuality of both shape and colour change may be that we own less items of clothing in the future but pay more for them. Perhaps new, smart or adaptive technologies will slow down the pace of fashion.

Implications for end of life

A single item of clothing can be made of many components; each component can be made of several types of polymer. A typical outerwear jacket is composed of an outer shell, insulation material, lining, zips, pulleys, Velcro fastenings, studs, buttons, etc. This type of mixed composition presents a great challenge to any efforts to recycle or reclaim the product because they create fabrics that are bulkier and of low aesthetic value, quality fibres can only be reclaimed from 100% compositions.

Garments made from 100% wool or cotton can be successfully processed into new garments. Reclamation of wool fibres on an industrial scale dates back to 1813. A process that involved the grinding down of old clothes into fibres that could be re-spun into yarns grew to be known as the UK's shoddy industry that originated in West Yorkshire. Although recycled fibres are of inferior quality when compared to new or virgin fibres, they provide cheaper raw materials. Wool garments labelled 100% Wool suggest quantities of recycled fibres are present in the garment, while products bearing the Woolmark logo indicate that the item contains 100% pure new wool or *virgin wool*.

Italian textile mill Calamai (founded 1878) has been producing commercial volumes of recycled wool since 1921, more recently commercial quantities of reclaimed cotton fine single jersey.

The logistics involved in isolating fibre and other material groups in composite garments make it impossible to recycle useful parts either by introducing them back into products or allowing them to biodegrade. It is well known that synthetic polymers such as Polyester, Nylon and Polyethylene do not break down easily, are difficult to recycle and usually end up in land fill sites, scientist estimate this can take 500-1000 years. We are all haunted by images of seals, dolphins and other sea creatures choking on synthetic webbings and bags from the floating islands of plastic waste. Biopolymers are synthetic materials designed to imitate the useful properties of Nylon, polyester etc but are also able to decompose in either composting or landfill sites. These polymers can be extracted from sustainable, non-fossil-fuel, cellulosic sources classified as agricultural waste (i.e from sugar beet, corn and wheat). A commercial example is Ingeo®, these textiles are made from Polylactic acid (PLA) manufactured by US company Natureworks.(now owned by Japanese polymer giant Teijin)

In 2007, the American synthetics pioneers du Pont launched Apexa® a biodegradable co-polyester resin as an alternative to PLA. This particular polymer can be used in the formation of melt spun fibres as well as buttons, zips and tape to produce a composite garment system from a single polymer. This is a very significant innovation that proposes solutions to both issues of multiple compositions in garments and biodegradability and paves the way for biomimetic design that uses material assembly and structure to engineer functionality as opposed to inherent material properties. Japanese sportswear manufacturer Goldwin launched a clothing range in Febuary 2008 using the Apexa polymer (have contacted them for images)

Biomimetics can show the textile industry ways of using design to achieve desired functionalities over material properties. For instance: insulation properties are engineered into man-made textiles using hollow fibre-cross sections. A team of researchers headed up by Dr Richard Bonser at the Centre for Biomimetics based at Reading University in the UK are studying the insulation mechanism of various forms of down feather; initial findings reveal that heat insulation properties are independent to the material composition of each feather type and directly related to the feather structure. The team plan to extract the design principles from the feather and interpret it into sophisticated insulation technology able to be reproduced in any textile polymer.

Biomimicry of functional surfaces

There is a lot we can learn from the way functionality is executed in natural structures. It is seldom the case that natural mechanisms or structures carry out a single operation; *multi-functionality* is essential to survival in the natural environment. The shell of a dung beetle is an exoskeleton that protects the insects internal organs from impact, it also provides structure to the organism. The texture or surface morphology of the shell prevents adhesion and wear (Nagaraja and Yao, 2007). Surface texture is used commonly in natural materials and structures to provide an array of additional functionalities. Hydrophobicity is another common property attributed to surface morphology often found on insect wings. Clever surface design prevents water from adhering to the wing structure.

Surface induced hydrophobic behaviour is used to serve many purposes in both the animal and plant world. The lotus plant lives in muddy environments yet remains relatively clean. Droplets of water simply roll of the leaf surface due to its hydrophobic nature. Drops of rain water roll along the surface of the leaf, taking with them particles of dirt, thus the plant is able to clean itself without any additional energy input. The mechanism that delivers this self-cleaning property was discovered by Biomimetic scientists Barthlott and Neinhuis from the University of Bonn in 1975. Dubbed the ‘Lotus Effect’, the technology has since been interpreted into masonry paint (Lotusan) and more recently a textile finish[i].

The application of Lotus Effect to garment textiles means that clothing are resistant to stain or soiling, this offers an alternative technology to the highly toxic current industry methods such as Teflon coating. This process involves the coating of fibres or textiles with compounds made from silicone or organofluorochemicals (Slater 2003).

Clothing resistant to staining or dirt require less maintenance. The energy required to launder a specific item of clothing would significantly reduce. Outerwear garments such as coats or jackets could self clean in rainy conditions. The Lotus Effect is also an invisible technology; it causes no apparent changes to the appearance handle or feel of the textile so introduction into the mass market would not be hindered from this perspective. However, the technology currently commands a premium, consumers need time to assess/ evaluate the benefits and justify the extra cost.

Biomimicry of structural colour

The introduction of colour through pigment based printing and dyeing is another of the industry’s most polluting activities (Slater 2003). Non-hazardous synthetic dyes are a key area of development, alternatively we can draw inspiration from the way colour and pattern is engineered in nature.

There are two mechanisms used to produce colour in the natural world. Pigment, defined as a material that alters the colour of transmitted light by absorbing specific wavelengths and is found widely in animals (i.e. skin, hair, eyes) and plants (i.e. leaves, flower petals, roots). Structural coloration is managed by the morphology of the biological surface using interference of reflected light to generate colour (Rossbach et al., 2003). The mechanism is found in some butterfly wings and in more complex systems that combine both mechanisms (i.e. cefalopods).

Morphotex TM by Japan's Teijin Fibre Corporation is a new biomimetic fibre using structural coloration. The technology is based on the design of the wing of the South American Morpho butterfly. The fibre surface is engineered using 61 alternating nylon and polyester layers to produce colours such as iridescent blue, green and red without the use of pigments. The introduction of this technology into fashion would result in ranges of garments that demonstrate a new colour aesthetic. Unlike conventional iridescent fibres that 'sparkle', Morphotex offers paler tones never before used in fashion. Unfortunately, this product is not commercially available because the current market demand is not strong enough to warrant sustainable production volumes.

Conclusion

Biomimetics is a platform that facilitates the transfer of technology from nature to the man-made world. Initial outcomes are innovations such as Lotus Effect and Morphotex that offer useful functionalities able to reduce the impact of textile and garment production on the environment. The reproduction of these technologies on an industrial scale has been successful because they require relatively small modifications to existing industrial processes. In the future, further advances in technology will enable the clothing industry to transfer even more paradigms for sustainable manufacture Ultimately it is the consumer, often an unpredictable force, who seals the fate of any innovation.

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[i] See Black, S Nanotechnology: application in sustainable textiles, in Sustainable Textiles , ed Richard Blackburn