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Biomimetics and the design of outdoor clothing

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Abstract: Biomimetics is the transfer of technology from biology into the man-made world; this chapter focuses on applications specific to outdoor clothing. An introduction to the discipline along with some key developments is followed by an outline of the requirements of clothing performance specifically designed for protection in cold outdoor conditions and examples of biomimetic technology that offers such functionality.

Key words: biomimetics, protective clothing, adaptive textiles, physiological comfort.

6.1 Introduction

During the 1930s, Otto Schmitt coined the term *biomimetics* in his doctoral thesis, to describe an electronic feedback circuit he designed to function in a similar way to neural networks, this invention later became known as the *Schmitt Trigger*. Over the coming years several synonyms such as *bionics*, *biomimesis*, *biomimicry*, *biognosis* cropped up in various parts of the world to describe developments inspired by the functional aspects of biological structures. Biomimetics is a compound word of Greek origin: bio- meaning life and -mimesis meaning to copy: the outcome is the interpolation of natural mechanisms and structures into engineering design. The cross-disciplinary nature of the field has established a platform for technology transfer that transcends subject specific ‘cultural’ barriers such as technical language thus functioning as a vehicle for ideas from biology to find useful applications in other fields.

Several historical examples are believed to be inspired by natural mechanisms, such as the design of the Eiffel Tower and the glass roof of the Crystal Palace that housed London’s Great Exhibition of the 1850s. The first textile innovation linked to Biomimetics was the invention of the dry adhesive tape known as Velcro that was inspired by the hook mechanism found on the surface of burrs which enables them to attach onto animal fur in a way that is difficult to remove. However, such examples are probably serendipitous; biomimetic innovations today are the product of systematic study, with wide-reaching applications.

This chapter focuses on the role of biomimetics in outdoor clothing applications. An introduction to the discipline along with some key developments is followed by an outline of the basic requirements of clothing functionality specifically designed for protection in cold outdoor conditions. Opportunities for biomimetics are illustrated using some current developments that highlight the potential for innovation.

6.2 Inspiration from nature

Biology has always been a rich source of visual and aesthetic inspiration for the design of clothing, common to every culture and era. There are countless examples of motifs such as flowers, insects and various animals, incorporated into the design of textiles either through structural patterning (e.g. jacquard weave), print or embroidery. Elaborate floral motifs expressed in print, embroidery and embellished with precious stones is a key trademark of London Fashion Week designer Mathew Williamson. The replication of animal markings such as the 'leopard print' has become a trademark for Italian fashion house Dolce & Gabbana.

Man has sourced materials for clothing since prehistoric times and gradually developed sophisticated technology that enabled survival in the most extreme conditions. Ancient Inuit hunters for example, used the protective functionalities of seal and bird skins in their clothing systems to create the highly insulating and water resistant clothing necessary for survival in the freezing conditions of their natural habitat (Ammitzboll, Bencard *et al.* 1991).

The desire to transfer various properties from biological materials to the textile sector is not entirely novel. In fact attempts to imitate the functionality of silk have led to great turning points in the history of textile technology. The strength and lustre of the silk fibre was the object of man's obsession for centuries. Efforts to synthesis a material that imitates these properties date as far back as 3000 BC in China. It was not until the early twentieth century that these efforts were successful and the first man-made fibre, Rayon, was mass produced. Although rayon imitated the lustre of silk, it lacked its strength (Cook 1984). It was not until a few years later that the industry was revolutionized with the mass production of synthetic fibres.

The first synthetic fibre was commercially produced in 1939 by E.I. Du Pont de Nemours and Company. Following an extensive research programme, the company synthesized a polyamide fibre they branded Nylon. Nylon fibres were long, smooth and offered a silk-like handle to textiles but with much superior tensile strength. (Handley 1999).

By the 1950s more synthetic fibres were commercially produced such as polyester and acrylic. Unlike natural and regenerated fibres, they absorb only nominal quantities of moisture (Cook 1984) creating quick drying textiles that require no ironing. Crisis struck the synthetic fibre industry in the 1970s as consumers rejected products made from these fibres and sales plummeted. The fibres caused a range of new discomfort sensations such as cling, clammy, static and various skin irritations (Kemp 1971). The hydrophobic nature of synthetic materials that created a revolution in the 1950s was the cause of their demise twenty years later as consumers began to favour the properties of natural fibres over their synthetic counterparts.

The 1970s was a very important time for the textile industry. During this decade great losses were made in the man-made fibre sector which drove researchers to investigate the causes of comfort/discomfort and technologists to find ways of manipulating the performance of synthetic materials to imitate the properties of natural fibres. By the end of the 20th century synthetic fibres had made a total recovery in the clothing sector and in some cases, synthetic textiles could command higher prices than those made of natural fibres (Handley 1999).

The application of biomimetic technologies in the clothing sector has resulted in the introduction of new functionalities to garments such as performance enhancement. Speedo pioneered a range of swimsuits branded FastSkin that use a textile system with small ridges designed into the surface texture of the textile, similar to the surface morphology of shark's skin. Sharks can swim remarkably fast for their size and shape, the simple mechanism in the texture of the animal's skin is believed to reduce drag thus increasing speed. Speedo claims that the FastSkin product can offer this functionality to a swimmer. Although there is no scientific evidence proving the textile system's functionality, the products have become widely accepted by athletes internationally.

Biomimetic technologies also offer ideas for new methods of implementing existing processes such as stain/soil resistance. The Lotus effect, for instance, was inspired by the water-repellent and self-cleaning properties of the lotus leaf. The functionality was found to be due to a layer of epicuticular wax crystals that covered the sculptured surface of the leaf (Barthlott and Neinhuis 1997). Originally this mechanism was interpreted into technology adopted by the paint industry to produce a paint that would self-clean every time it rained. Recently, this has found application in the textile sector as a finish that delivers water, stain and dirt resistant properties to clothing without affecting the appearance or handle of the cloth. Although there are conventional finishing processes that achieve this effect (e.g. Teflon coating), they use highly toxic chemicals, whereas the methods (e.g. plasma treatment) used to create the Lotus effect are low energy thus offering an environmentally sound alternative (Slater 2003).

6.2.1 Biomimetic principles and methods

Our knowledge of evolution depicts the natural environment as a testing ground for design and development in nature. Selective pressures are exerted onto the organisms of an ecosystem, for example, through limited reserve of nutrients vital to sustain life. In order to survive, plants and animals evolve mechanisms and structures that enable them to make optimal use of minimal resources

(Beukers and Hinte 1998; Vincent, Bogatyreva *et al.* 2006), thus successful ‘design’ survives and bad ‘design’ disappears.

The link between energy/resource in nature and cost in engineering is believed to be a common agenda between design in biology and engineering. The optimization of limited resources in biological materials and structures was originally interpreted as opportunities to develop clever yet cheap materials and structures (Beukers and Hinte 1998). This notion of energy = money evolved to encompass the greater cost to the environment and the consumption of natural resources in the construction of man-made products (Benyus 1997). Biomimetic scientists today believe nature is a rich source of clever and sustainable design that can offer new properties as well as clean methods for existing processes.

Functionality through design

Engineers rely on material properties to deliver desired functions such as stiffness, strength or elasticity to structures. Functionality in biological materials is incorporated into the structure through the design and distribution of basic building blocks (Benyus 1997; Beukers and Hinte 1998). Whenever a new property is required in the man-made world, a new material is usually synthesized; as a result there are over 300 man-made polymers currently available. There are only two polymers in the natural world – protein and polysaccharide – whose structural variations offer a vast range of properties superior to their man-made counterparts (Vincent, Bogatyreva *et al.* 2006). Insect cuticle, for instance is made from chitin and protein and can demonstrate a host of mechanical properties, it can be stiff or flexible, opaque or translucent, depending on variations in the assembly of the polymer (Vincent 1982).

Conditions of manufacture

The production of conventional man-made materials and structures is generally a ‘costly’ procedure in terms of energy consumption and resource waste. Extreme temperatures, pressures and toxic chemicals are often required during production. Man-made fibres are a prime example of ‘high-energy’, ‘high-waste’ production processes. Natural materials require low energy conditions for their ‘production’ and normal temperatures and pressures no different to those necessary for life. There is also no need for harmful chemicals; usually water is adequate for the creation and growth of structures (Benyus 1997).

Multifunctional/adaptive structures

Biological materials and structures are designed to perform multiple functions as a way of maximizing the use of resources. Key properties are introduced into a material or structure through clever design and application of available resources. The texture of a surface, for instance, is engineered to provide self-cleaning properties to a plant or animal. Functional surfaces often occur on the surface of leaves, to protect the plant from contamination; the Lotus mentioned earlier is a plant well known for this property. Several species of insect also employ the same principle to render their wings hydrophobic. A similar mechanism is found on the shell of the dung beetle providing anti-adhesion and anti-wear properties (Nagaraja and Yao 2007).

Multifunctional textiles are currently created by bonding layers of materials with different properties together to form a composite textile. Membranes such as Goretex and Sympatex are laminated with knitted or woven textiles to create multifunctional systems whose properties amount to the sum of the individual properties of each component. Often the outcome is a textile system predominantly used in outer shell clothing that offers breathable, wind and water resistance.

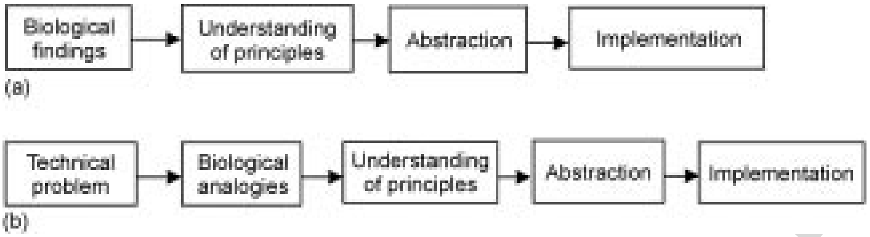
Adaptive

Biological materials are created by the organism and are in constant flux with the conditions in the environment, whereas their man-made counterparts are fabricated by external efforts (Hollington 2007). The design brief for man-made structures is predetermined and aimed to satisfy a specific set of requirements that remains unaltered during the useful life of a product. The structure of biological materials is defined partly by DNA and partly by the environment – ‘Nature and Nurture’. The survival of plants and animals depends on the ability of their structures to adapt to the changing demands of the environment; some key properties are self-assembly, reproduction, self-repair and redistribution of vital resources (Beukers and Hinte 1998).

6.2.2 Development models

Biomimetics is a relatively new field with a short history; as a result there is currently no standard methodological approach to the transfer of technology. A popular model is one adopted by the Biomimetic Guild that illustrates a linear progression of ideas from biology to engineering (Gester 2007). According to this method Biomimetic developments can follow one of two directions: bottom up or top down (Fig. 6.1).

The bottom-up approach (Fig. 6.1(a)) denotes a development or innovation that has been instigated by a single biologist or a team. The biologist(s) identify an interesting mechanism in nature they believe would potentially have a beneficial application in industry. The property is studied to create an understanding of the operational aspects of the mechanism. The principles are abstracted into a model that is taken up by a team of engineers who identify methods of interpreting the technology into useful man-made products.



6.1 Biomimetic development model: (a) bottom up, (b) top down (source: Gester, 2007).

The top-down process (Fig. 6.1(b)) is initiated by industry need or a gap identified in the market. This need or gap is defined in terms of a technical problem for which analogies are sought in biology. Once suitable paradigms are identified a process similar to the bottom-up approach is followed where a team of biologists study the mechanism(s), identify how they work and pass on the information to engineers who interpret the ideas into solutions to the technical problem.

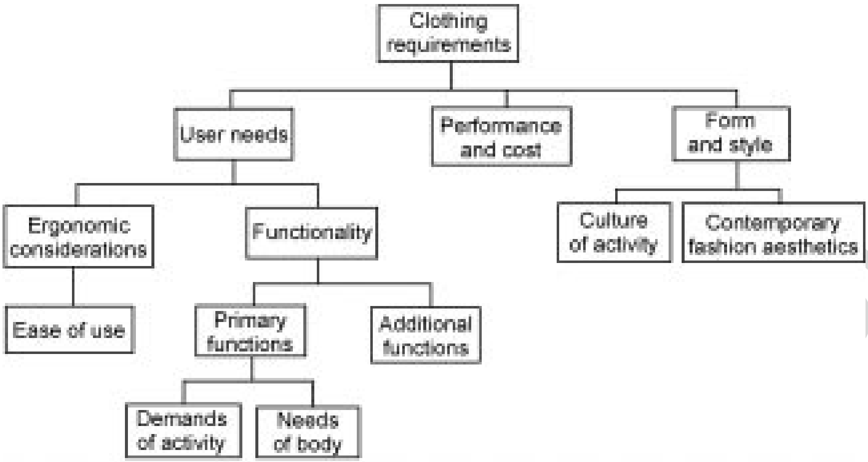
This model succeeds in creating a simple illustration that is reflective of the technology transfer process among many biomimetic teams today. However, it is limited by the fact that both bottom-up and top-down directions rely on a serendipitous and non-systematic approach to problem solving (Vincent and Mann 2002). An alternative model, currently under development at the University of Bath's Centre for Biomimetic and Natural Technologies, has adopted TRIZ (Russian acronym for Theory of Inventive Problem Solving) framework, a verified methodology used by engineers for decades that offers a systematic approach to the definition and solution of problems. Researchers at Bath University are currently developing this tool (Vincent, Bogatyreva *et al.* 2006).

6.3 Biological paradigms for outdoor clothing

There are a number of opportunities for biomimetics with specific applications in outdoor clothing and the factors affecting the physiological comfort of the wearer. An overview of garment requirements is followed by developments in the biomimetic sector that can offer innovation to the design and performance of clothing for the outdoors.

6.3.1 Clothing system requirements; overview

A clothing system can be made of one or more layers (base, mid, external shells) extending from the surface of the skin to the face of the outer garment creating a portable environment (Watkins 1995) of fibrous material and air. The role of the system is to satisfy the physiological and psychological needs necessary for the individual to function within the physical and social environment. The dynamic



6.2 Clothing requirements (source: Black *et al.*, 2005).

micro-climate created within the system controls the physiological comfort of the wearer and is influenced by external factors (climate, activity of wearer, etc.) and internal factors (fibre properties, textile structure, design of garment, etc.) (Black, Kapsali *et al.* 2005).

The end use of the system dictates whether emphasis during the design and development is placed on the physiological or psychological functionality of the clothing, however all garments must satisfy some basic requirements (Fig. 6.2). The form and style of each item within a clothing system must suit the culture of the activity and meet basic contemporary design aesthetics Black and Kapsali (2005). Clothing must also satisfy basic ergonomic considerations to avoid inhibiting general activities and functions. It is vital that each item of clothing is easy to use (adding and removing garments) and does not restrict movement. The product also needs to balance performance with cost; successful design convinces the consumer that its price is suitable to the performance of the garment.

Additional functional requirements represent possible future demands from clothing enabled by new and emerging technologies. The advancing fields of bio-, nano-, electro- textiles are introducing new properties to apparel that could supplement the functionality of conventional clothing to meet changing needs of the consumer's lifestyle. Remote connectivity, for instance, enabled by innovations in wearable electronics offers clothing able to take on additional roles currently performed by devices such as mobile phones, PDAs and satellite tracking devices.

In the context of clothing engineered for protection in outdoor activities, the most important factor in the determination of the functional profile of the system is the external conditions that affect the physiology of the user, i.e., environmental temperature, moisture concentration in the atmosphere, weather conditions (rain, snow, sun, wind). Protective functionalities associated with psychological hazards and other potential hazards such as microbes, chemicals, physical impact, etc., are not exclusive to cold weather clothing and will not be discussed in this chapter for purposes of simplicity.

From the perspective of the wearer, the preservation and protection of physiological comfort is paramount and relies on the flexibility of the clothing system to accommodate changes in the system's microclimate as well as protection from external factors (wind, rain, snow). Garments engineered for protection in cold weather must retain enough heat within the system to ensure the wearer's comfort while at the same time manage the penetration of water and cold air from the external environment and moisture produced by the individual.

The design and selection of materials composing the clothing system are the key factors in the management of microclimate conditions. The clothing system's permeability to heat, moisture and air can be controlled to a certain extent by the properties inherent in the materials used for the composition of the garment and various design features.

Design features

Collars, cuffs and belts are some structural features that enable the management of a garment's insulation properties by trapping volumes of air. Layering is another technique used to vary the insulation properties of a system; more layers equate to more trapped air thus more insulation. This technique is the most flexible for accommodating any changes in external conditions or wearer activity. The individual assesses the level of insulation required to maintain his/her levels of physiological comfort and adds or removes layers accordingly.

It is well known that saturated air trapped in the microclimate is the key factor causing physiological discomfort. This is often the problem with clothing that offers high insulation. Design features such as zips and openings enable the saturated air to be replenished, a method known as periodic ventilation (Ruckman, Murray *et al.* 1999). A prime example is the design of traditional Inuit clothing that was made from highly insulating furs and feather pelts that offered protection from the extreme conditions of their natural habitat and ensured their survival. Although the materials used to construct the garments offered the necessary insulation properties, it was clever design of the upper garment that enabled extremely efficient ventilation to accommodate changes in the individual's activity (Ammitzboll, Bencard *et al.* 1991; Humphries 1996). The traditional Inuit hood was closely fitted around the face with no front opening and air was trapped in the system at the chin and waist. The sleeves on the parka were long enough to cover the hands and fitted to prevent cold wind from penetrating the system. During periods of activity when the microclimate was threatened by saturation, ventilation was achieved by pulling the garment forward at the front of the throat, pushing the hood back or loosening the closure at the waist (Humphries 1996).

Textile properties

There are several methods used to manipulate the permeability (heat, air, moisture) properties of a textile structure; the shape or cross-section of a man-made fibre, for instance, can be engineered to trap air (i.e. hollow fibres) or to introduce a crimp along the length of the fibre (imitating the morphology of wool fibres) to increase the volume of air trapped when applied to a textile. A fibre can also be designed to maximize the rate of moisture evaporation by increasing the surface area. A popular example is the Coolmax fibre whose cross-section is often said to represent Micky Mouse ears. This particular configuration is calculated to increase surface area by 30% compared to a standard circular cross-section of the same diameter. Cellular and double knit/weave structures can maximize the insulation properties of the textile while the tightness or openness of the structure affects air permeability while wind and water resistance can be managed by the incorporation of specialist membranes into the textile system. These are a few examples indicative of the sector and by no means exhaustive.

6.3.2 Opportunities for biomimetics in the design of cold weather apparel

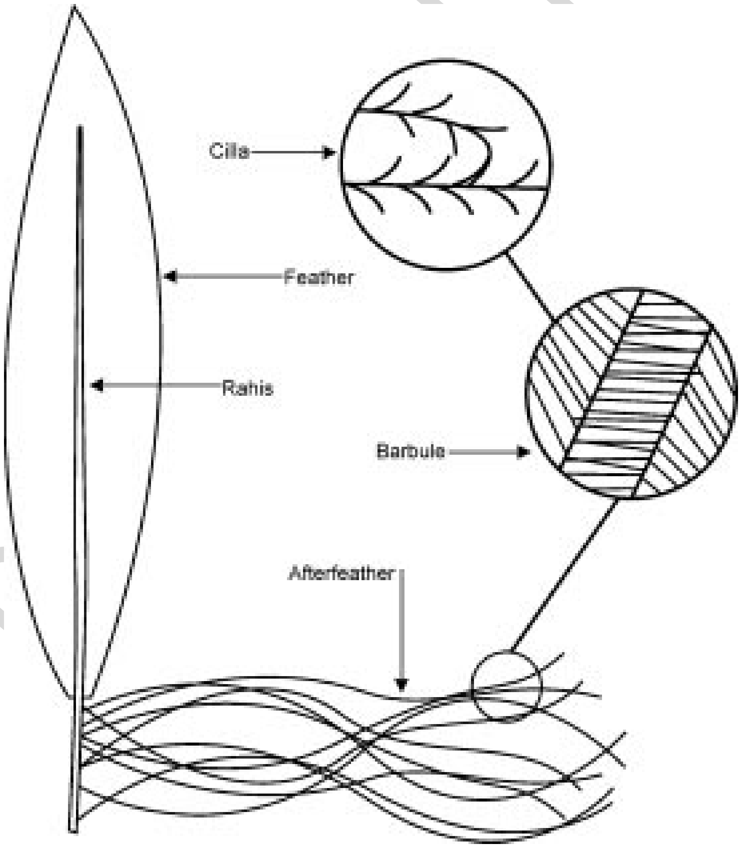
Conventional clothing systems require the wearer to initiate any adaptation to heat, air and moisture permeability, this method poses several limitations such as the ease involved in the removal and storage of necessary layers of clothing during wear and the individual's ability to sense the onset of physiological discomfort. It is often the case that the cue for adaptation is the discomfort sensation itself; this can be prevented if the system's properties are adjusted in response to initial changes in the microclimate before the temperature and moisture concentration reaches a point where discomfort occurs. A clothing system with the ability to sense changes in the microclimate and alter its properties without the intervention of the wearer would be ideal. Materials and structures in biology rely on adaptive mechanisms that respond to changes in environmental moisture and temperature for survival.

Adaptive insulation

During the 1990s a team of British biomimetic investigators at the University of Reading became fascinated with penguins and their ability to survive in extreme conditions. Penguins must withstand extreme cold for up to 120 days without food and then be able to dive up to 50 m into freezing waters in order to feed. The team found that the secret behind their survival was the structure of their coat (feather and skin combination) and its ability to switch from an insulating barrier to a waterproof skin.

When necessary the penguin coat provides highly efficient insulation that minimises heat loss through radiation and convection, with structural properties that function as an excellent wind barrier eliminating heat loss though convection. Yet when the animal needs to dive for food, the coat transforms into a smooth and waterproof skin eliminating any trapped air. This switch in functionality is achieved by a muscle attached to the shaft of the feather, when the muscle is locked down the coat becomes a water-tight barrier and when released the coat transforms itself into a thick air filled windproof coat (Dawson, Vincent *et al.* 1999).

The feathers in a penguin's coat are packed evenly over the animal's body averaging between 30 and 40 per cm^2. Dawson, Vincent *et al.* (1999) identified that the mechanism responsible for the remarkable insulation properties are found in the afterfeather (Fig. 6.3). The afterfeather consists of approximately 47 barbs averaging 24 mm in length. Each barb is covered with around 1250 barbules that are about 335 μm in length. This structure creates airspaces of



6.3 Penguin feather (source: Dawson *et al.*, 1999).

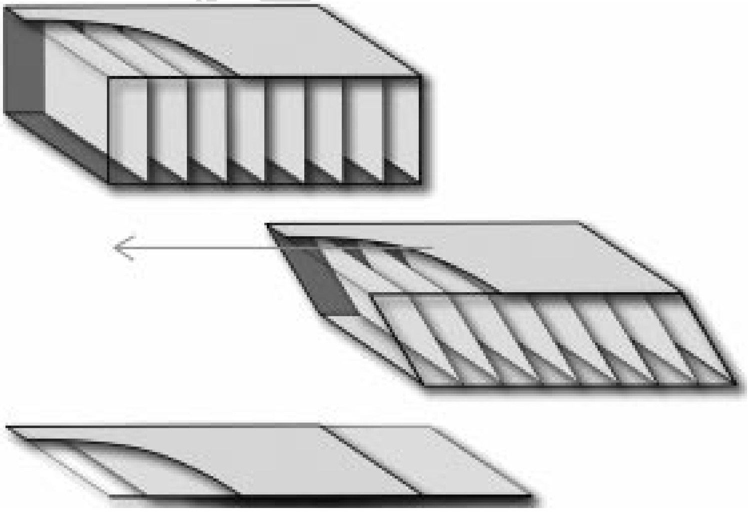
around 50 μm in diameter, which provide an enormous surface for trapping air thus creating a structure capable of providing such high levels of insulation.

A key factor in the success of the adaptive mechanism is the ability to recreate a uniform division of air space every time the coat's functionality alters from waterproof to high insulation. The mechanism that enables this is found on the surface of the barbules; Dawson, Vincent *et al.* (1999) noticed that tiny hairs known as cilia (Fig. 6.3) covered the barbules that function as a stick slip mechanism to keep the barbules entangled and maintain the movement in directions relative to one another to ensure uniformity in creation of air pockets during the coat's function change.

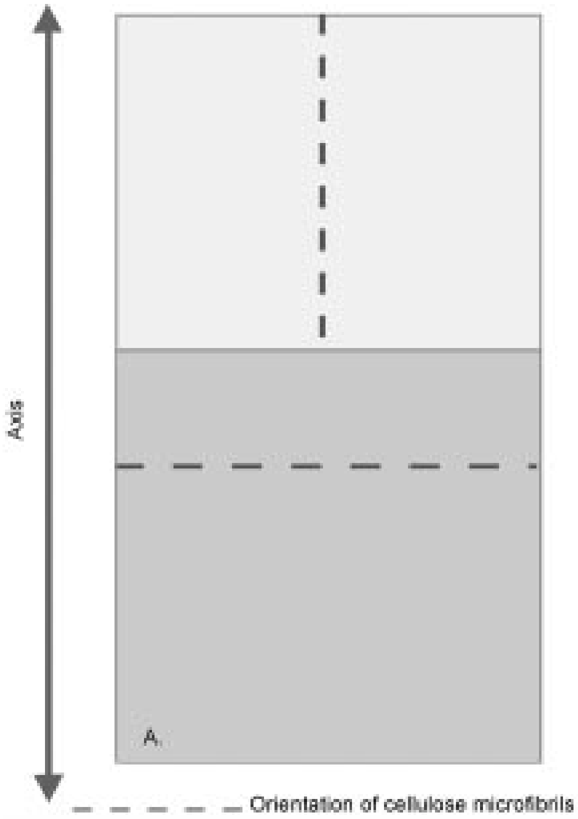
The insulation properties of the penguin coat adapt by varying the volume of air trapped within the system by drawing the feather towards the skin when the waterproof functionality is required and releasing it when the penguin needs to be kept warm. Attempts to interpret this functionality into garments has led to the creation of an experimental textile system referred to as *variable geometry*; some development has been carried out by N. & M.A. Saville Associates (Figs 6.4 and 6.5).

The structure consists of two layers of fabric, which are joined together by strips of textile at an angle to the plane of the two fabrics. By skewing the two parallel layers the volume of air between them reduces, this results in the reduction of thermal resistance. The idea was used in the design of military uniform systems that can be adapted to function in both extreme cold and hot conditions.

Adaptive insulation has recently been commercialised by Gore & Associates who have created an ePTFE membrane and polyester structure (76%PE



6.4 Variable geometry textile.



6.5 Bilayer configuration.

24%PTFE) used as a garment insert under the brand name Airvantage. This product allows the user to inflate/deflate the jacket thus controlling the necessary amount of air for the provision of adequate thermal resistance.

Solar radiation for advanced thermal protection

The brilliant white coat of the polar bear provides effective camouflage in his arctic habitat and conceals him from his prey. The pelt is an extremely effective mechanism that supports the animal's thermal regulation by insulating the animal for extreme cold conditions.

Grojean, Sousa *et al.* (1980) studied the mechanism and found that the pelt itself consists of thick hairs approximately 100–150 μm in diameter and 6–7 cm in length, a dense layer of fur about 1 cm long with fine fibres (25–75 μm), these are attached to a thin layer of black skin approximately 1 mm thick. There has been little study on the structure of the polar bear fur but it is believed to trap air and prevent heat loss in a similar way to the pelts of other animals; however, the absorption and conversion of solar energy is attributed to the morphology of the longer, thicker hairs.

The hairs are hollow in structure along their length and taper to a solid edge at their tip. Although they have a smooth external surface, the core is very rough while the hairs themselves contain no pigmentation. The air pockets created in the hair's core offer additional insulation while Grojean found that the light energy from the sun is drawn into the core of the hairs and the anomalous surface scatters the energy downwards toward the skin. This 'solar lumination' system absorbs UV light from the sun to support the animal's temperature regulation. As a result polar bears require 12–25% less effort to maintain a comfortable temperature (Grojean, Sousa *et al.* 1980).

Hollow fibres are extensively used to engineer highly insulating garments, sleeping bags and other products for cold weather protection. The concept of using textile systems to reflect heat to or from the body has recently been implemented into textiles using thin aluminium films or textiles impregnated with ceramic particles. Additional heat can be introduced into a clothing system via heating elements in electronic textile configurations and paraffin filled phase change microcapsules (PCMs by Outlast); both products are limited to the provision of a finite amount of heat energy dictated either by the power source (electronic textiles) or capacity to store heat energy (PCMs). Although there are no existing developments using polar bear hair as a model for technology transfer, advances in optical fibres could enable the interpretation of solar illumination technology into clothing and other systems to provide additional 'free' heat in extreme cold environments.

Smart microclimate ventilation

The replenishment of saturated air is a key factor in the maintenance of physiological comfort. Open textile structures such as loose weaves and knits allow the movement of air between the microclimate and the environment. Although these structures provide effective ventilation, heat is lost to the environment creating a system that provides poor insulation. In the case of clothing for cold weather protection, it is essential that textiles prevent cold air from penetrating the system. Currently, ventilation of cold weather clothing can only be achieved manually with the aid of design features such as those discussed earlier.

Membranes such as Diaplex by Mitsubishi Industries and C-change by Schoeller are made from a type of polyurethane that is claimed to alter its porosity to moisture at different temperatures. These products are ideally situated on external layer garments as they can respond to changes in external temperatures; cold environments require less porosity from the clothing while an individual would benefit from a more porous garment in warmer conditions. Temperature changes in the clothing microclimate are not as representative of comfort sensation as moisture concentration (Li 2005) especially during higher levels of activity. These products are therefore ideal for low-level outdoor activity.

Several plants use environmental moisture conditions to trigger seed dispersal. These hygroscopic mechanisms hold some ideas for creating textile structures that can alter their permeability to air in response to changes in humidity. Work conducted by Dawson in 1997 as part of the Defense Clothing and Textiles Agency (DCTA) studied the opening and closing mechanism of the pinecone that is triggered by changes in environmental moisture concentration.

Dawson, Vincent *et al.* (1997) found that the bract is composed of two types of wood one type (active tissue) demonstrated great dimensional swelling when exposed to moisture while the other remained unaffected. Although both types of wood were constructed from cellulose, the microfibrils in the cell wall of the active tissue type are positioned at 90º to the axis of the bract (Fig. 6.5) while the microfibrils in the other type are orientated more or less parallel to the central axis (Harlow, Coté *et al.* 1964). The coefficient of hygroscopic expansion was found to be three times greater in the active cells than that of the non-swelling tissue (Dawson, Vincent *et al.* 1997) which explains the greater longitudinal swelling shown by the active tissue. Dawson noticed that the mechanism operated in an analogous method to a bimetallic strip where the switch was ambient moisture content instead of changes in electrical current (Dawson, Vincent *et al.* 1997).

A textile system was developed using a light-weight synthetic woven structure laminated onto a non-porous membrane such as those marketed under the Sympatex brand. Small u-shaped perforations were cut into the surface of the composite textile demonstrated in Fig. 6.6(a). An increase in relative humidity caused the loose sections of fabric created by the incisions to curl back (Fig. 6.6(b)) thus increasing the system's permeability to air. When the microclimate becomes damp the textile alters its porosity to allow the renewal of saturated air, the structure resumes its original properties when conditions near the skin are dry and ventilation is no longer required. Nike recently implemented a similar concept into a clothing system; the technology was incorporated into a tennis dress worn by Maria Sharapova at the 2006 US Open. The garment featured a fish scale pattern on the back panel that opened up as the athlete perspired to increase local ventilation and maintain the wearers comfort.[1]

Researchers at the University of Bath have developed a prototype textile based on the work of Dawson that applies the principle to a yarn able to increase the porosity of a textile structure in damp conditions and reduce permeability when dry. This technology is currently being developed for applications in the commercial sector.

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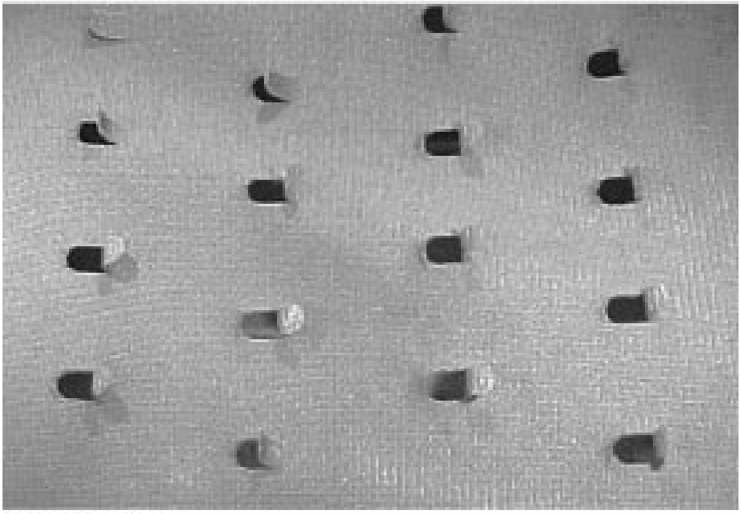
[1] US Patent Application 20050208860.

(a) Dry conditions



(b) Damp conditions

6.6 Adaptive ventilation textile: (a) dry conditions, (b) damp conditions.

Functional surfaces

Nature uses surface texture as a tool to introduce important functionalities that protect the organism from contamination, impact, etc. The self-cleaning properties of the lotus leaf, discussed earlier, have been interpreted into paints for building exteriors, finishes for textiles and more recently a coating for window glass panes. Superhydrophobic surfaces are used in textiles to protect garments from dirt and liquid contamination as well as penetration from water. This functionality can be extended to benefit cold weather apparel, sleeping bags, tents, etc., especially in rain or snow; droplets of water simply roll off the surface of the article preventing the structure from moisture penetration while removing dirt or other contaminants in their path.

6.4 Future trends

The boundary between wearer and clothing is undergoing a reform fuelled by advances in material science and technologies that could have been extracted from science fiction. Shape-memory alloys are used to alter the shape of a garment in response to heat or electrical currents. Microcapsules filled with various substances such as essential oils and synthetic wax can be incorporated into clothing through foams and fibres. Washable electronic circuitry is integrated into clothing through textiles that enable the system to operate as a mobile phone, MP3 player, GPRS etc. Some futurologists even predict that garments of the future will imitate the behaviour of living organisms able to adapt, self-heal and even reproduce (Tastuya and Glyn 1997).

For new innovations to integrate successfully into the clothing sector, technology push needs to be met by consumer pull. There is little value in introducing functions to clothing that the consumer is not ready for or indeed needs. It is possible that consumer expectation from apparel will evolve; individuals will require their clothing systems to sense and respond to changes whether they are physiological or psychological.

Traditional clothing for protection in cold weather requires the wearer to manage the functional profile of the system either by adding/removing layers or by using openings designed into the garment, this is often not practical or initiated once discomfort sensations are well established, which is too late. This chapter has examined a range of biological paradigms that would improve the existing ‘state of the art’ in the cold-weather sector, it should be noted that the technology discussed is not limited to garments and can be adapted to accessories (shoes, gloves, etc.) and other apparatus (i.e. shelter, portable storage systems) Although some of the technologies discussed are at prototype stage and require significant development before they can enter the commercial sector, they offer a glimpse of potential properties of cold-weather clothing in the future and highlight the significance of adopting ideas from nature.

6.5 Sources of further information and advice

- Centre for Biomimetic and Natural Technologies at Bath University
  http://www.bath.ac.uk/mech-eng/Biomimetics/
- Biomimetics at Reading University
  http://www.rdg.ac.uk/Biomim/

- Online resource from the US-based Biomimicry Institute http://www.biomimicry.net/indexbiomimicryexp.htm
- German Biomimetic network http://www.biokon.net/index.shtml
- Biomaterials Network http://www.biomat.net/

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