1. Introduction

The military and sport worlds are often experimentation fields for innovative research in textile. The military, the sportswear and sport goods sector of the textile industry have resulted in market diversification for fibrous materials and at the same time upgraded textile science and technology to a level which become in par with other high-tech industrial sectors. New technological developments, fragmented niche markets and increasingly demanding customer expectations are just some of the factors relentlessly driving these industrial sectors. Good thermal properties for cold-weather sport; aerodynamic properties for cycling, swimming and skiing, adaption and breathable waterproofing for outdoor pursuit, body fit are some properties of high performance sportswear. With the advent of smart textiles and focus on functional design, the broad range of innovations has become name of the game for the military and sportswear businesses. And a lot of these innovations are extrapolated to casual and fashion clothing.
Buzzing items such biomimetica, adapting, smart, alarming, multifunctional, active and high-performance textiles are dealing with new materials such as nanofibres, biopolymers, shape changing materials, self healing coating, microclimated textile, smart coatings, luminescent phenomena, biomedical fibrous assemblies, emerging technologies and so on. The hi-tech performance of these new textiles, and their flexibility as well as versatility (for example they can easily be bent, or shaped into a 3D structure) have led to a worldwide and booming interest in such materials, and in a race for research and developments to push the limits of technology further. They have huge potential resulting in new products, new end uses and business opportunities. Some developments and related diversities in functional textile are striking but their impact, both visually and in the way they connect people to places and objects is much more so.

**Research focus on**

- **Passive**
  - Barrier against wind, rain, cold, heat, stretch, abrasion
- **Active**: Sensoric, adaptive, self-healing ...

**Comfort**
- Thermo physiological comfort
- Breathability
- Micro climate
- Dynamic wicking humidity
- Accelerated evaporation
- Sensorial comfort
- Non stickiness to skin, non-allergic..
- Aesthetical comfort
- Quality fit – body movement
- **Durability** (washing, ...)

*Figure 2: research items*

Contributing factors responsible for successful marketing of functional sportswear and sporting goods are the many advances made in the fibre and polymer sciences, and related production techniques. The finishing and coating/laminating industries have done pioneering work in the area of developing these technologies towards the needs of the sportswear and sporting goods sectors resulting in unique products.

*Figure 3: materials for smart clothing*
Today, polyester is the single most common fibre used for sportswear and active wear. Other fibres suitable for active wear are polyamide, polypropylene, acrylics and elastanes. Advanced spinning technologies such as bicomponent spinning, microfiber spinning result in specialty fibres (hollow fibres, sophisticated non-circular cross sections such as Coolmax) made a wider range of yarns commercially available for application in casual and performance clothing. Furthermore, biomass-based biopolymers and fibres such as chitosan (are Crabyon\textsuperscript{1}, Chito-Lio\textsuperscript{2} and Chitopoly) have been gaining ground in recent years as replacements for conventional petroleum-based products, due to concern over global warming and resource depletion. It is well known that chitosan possesses a wide range of useful properties such as antimicrobial and polyelectrolyte properties, thus lending itself to a variety of interesting clothing applications. The fibres are highly safe fibre, not containing any chemicals or allergy and are very gentle to the skin. They suppress the propagation of bacteria on fibres, even those exposed to perspiration, and prevent odours.

![Figure 4: temperature- en moisture management systems](image_url)

New advanced yarns with AM properties, with incorporated moisture management, stretch (from biconstituent or bicomponent fibres), UV-protection, heating effects give also a boost to the development of advanced clothing. In surplus R&D is going on in the field of biomimetic and fabric formation (3D-weaving, multilayer, knitting...) to introduce functional, intelligent and aesthetic functions. Advanced topochemical finishes, nanoparticles, coatings (self healing, SMP or shape memory polymers...) and monolithic breathable membranes (Gore-tex, Sympatex, Entrant, Diaplex...) contribute largely to performance and comfort issues.

T-controlled shape memory polymers (SMP, coating and membranes) are able to experience form/volume changes when exposed to magnetic field. New type of SMPs are developed where controlled shape changes are achieved in a contact-less fashion via externally applied magnetic fields. The strategy is based on the inductive heating experienced by

Finally, design requirements of active and performance clothing with adapted skills, knowhow in graphics, fashion and textile to conceive well-fitted and ergonomically and aesthetically pleasing viable ranges which take advantage of the latest progress in functional and smart textiles.

2. Recent developments in smart and advanced clothing

\textit{a) Aerotherm technology from PeakPerformance}

\footnote{www.crabyon.it}
\footnote{www.whanamtextile.co.kr/en/pro07.htm}
Aerotherm technology is based on aerogel insulation used in ski jackets and pants. The inside features a snap-in vest with a revolutionary nano-insulation technology called Aerotherm. Aerotherm was originally developed for NASA and space travel and is therefore capable of blocking both extreme heat and extreme cold. According to the company Aerotherm offers up to 8 times better thermal performance than any other material in the world, weighs just slightly more than pure air and doesn’t require loft to maintain its insulation capabilities like down or other synthetic padding. The jacket itself is constructed from our newly developed 3-layer HiPe fabric - HiPe Ace. It offers excellent breathability and durability, mechanical stretch for great mobility and a 20 000 mm water column.

**Figure 5: Aerotherm textile**

**b) Energear™ technology (Schoeller)**

Far Infrared Rays have numerous positive influences on energetic processes in the body. Far infrared treatments (coatings, prints) with a special titanium and mineral matrix on textiles ensure that the wearer’s energy is reflected back to the body bringing health and fitness benefits. This reflection can increase circulation and oxygen levels in the blood. According to Schoeller the additional energy can have various positive effects on the body, such as performance enhancement and the reduction of premature fatigue as well as improved regeneration. Furthermore, shorter warm-up phases suffice during physical activity and there is a general increase of concentration and wellbeing.

This development uses the ancient knowledge of the capacity of certain minerals to reflect back heat energy rays. Additionally, Far Infrared Rays have long been in use for medicinal therapeutic purposes.

The new technology allows the heat balance to be optimized and promotes various energetic processes in the body without having an effect on fabric proprieties such as breathability and elasticity. The technology is well fitted in clothing for all sports, summer and winter mountain activities, trekking, work wear and military, as well urban wear.

**Figure 6: Energear™ technology**

**c. Functionalized textiles with massaging and anti-stress effects.**
Research projects address to development of textile destined for old persons, or those have movement difficulties or manually handle weights aiming as well to improve well-being of people with sedentary daily activity by obtaining clothing with different compression, pressopuncture and massage effect.

Also in the sport world new developments take place focusing on massaging effects. Recently Puma developed new outfits for athletes. Italian Azurri and Swiss football players will wear the outfits at the World Cup this summer in Brazil. Nothing extraordinary at first sight, were it not that the shirts contain a special tape that gives the player the ‘micro-massage’. The manufacturer Puma shirts are fitted with so-called ACTV PWR technology for improved athletic performance. The silicone tapings incorporated in the fabric improves the blood supply towards the muscles. Other notable features of the shirts are a collar and a button closure.

![Figure 7: ACTV PWR technology (Puma)](image)

d. Intelligent compression sportswear

The development of their woven “intelligent compression” fabrics for swimwear like POWERSKIN Carbon Pro, the first racing suit integrating a carbon cage to deliver intelligent muscle compression, combined with unprecedented fit.

![Figure 8: Powerskin swimwear](image)

3. New ideas – new developments of smart clothing

Developments take place at a high speed with a great market potential in clothing sector. In active and endurance sports, performance is synonymous with comfort properties and often with protection of injuries. Also attention goes to sport equipment including attributes such as protective helmets, belts etc.
Also protective clothing and casual and even fashion clothing demand for high performance and comfort properties and attract greater research attention. Some examples are illustrated below.

3.1. Protective textile

*Textile for people with albinism.*

Albinism is a genetic condition and is caused by the lack or absence of melamin pigment in the body. The main function of melamin pigment in the skin is preventing damage of skin by absorbing UV-rays from the sun. Therefore, exposure to the sun is quite dangerous for persons with albinism. UV-protective textile based on the optimal selection of fibres, texture and finish with UV resistant (high UPF – UV protection factor) and breathable properties is essential for persons with albinism and living in places where sun arrays are effective. Today, the UV-property of natural dyes is investigated of some dyes extracted from potatoes, cabbage, tealeaf, strawberry, curcumin (antioxidant, anti-inflammatory) and amaranth.

The bi-functional of dyeing and UV-protection effect of natural dyes can be found and can bring out the potential usage of natural dyes on colored functional clothing.

Figure 9: advances in sportswear

Figure 10: a) chemical structure and powder of curcumin  b) amaranth flowers

Today comfort is not anymore a luxury aspect, it seems to be the opposite: a sufficient level of comfort is actually a basic requirement and a must, although this might be look easy but for workwear, sportswear and especially for protective clothing this can be a real problem. Many fabric and garment parameters influence comfort aspects. High temperature and quick metabolism increase the sweat production of human skin, especially during heavy activities. Because of this reason, both undesired smell and non-aesthetic appearance
can occur. Although deodorants have hazardous effect for human health and environment, they are generally used to overcome the problem. Better is to develop textiles using AM or functional microporous membranes which eliminate these inconveniences.

3.2. New Microcapsules – nano particles

a) Anti-stress, healing textiles

Stress, depression, sadness affect negatively the person’s mental state and health. Research aims to get benefit from the gem of natural amethyst’s anti-stress property health. Amethyst is purple quartz, and is a meditative and calming stone. It works in the emotional, spiritual, and physical planes to provide calm, balance, patience, and peace.

As a result of recent clinical trials antidepressant effect of Hypericum perforatum L. plants have been proven and their use has in the meantime widespread all over the world. New microcapsules are developed by incorporating the extract of Hypericum perforatum L in the core. A functional textile, which has an antidepressant effect could be designed by transferring these extract in the form of microcapsules into underwear clothing.

b) Hair care textile

Development of textile surfaces are conducted for providing hair care using microcapsules containing cysteine. New microcapsules based on the most abundant amino acid in the hair structure cysteine are developed and applied to textile substrates. These substrates can be used in hair-contacting products (scarfs, hat, bandana, beret etc.) and provide hair treatment functions.

c) Textile for skin cancer treatment

Developments, design and protection of fabrics using iron oxide nanoparticles for skin cancer treatment is going on in some European research institutes. Various scientific studies are conducted to examine the nano-sized features of this element. As a result of these studies, important scientific results about using of iron oxide nano-particles for diagnosis and treatment of some diseases have been determined. Research is underway to design and develop protective fabrics using these particles for treatment of cancer.

d) AM, insect repellant and allergic free textiles

Novel biobased plant nanoparticles are developed for providing coated textiles with efficient AM-resistance, insect repellant and allergic free properties. Medicinal or herbal extracts are used for the preparation of nanoparticles and to be coated on textile fabrics.

Another approach is the use of natural dyes as AM products. At present, banana peel and acacia bark as a waste by-product used for dye extraction are classified as medicinal, and some of these have been shown significantly AM-effects. The AM-effect is related to the existence of phenol, tannin and quinone in their extracts.

3.3. Bifunctional microcapsules – PCM’s

a) Temperature regulating textiles

Phase change materials can play a vital role due to their demands for in-built environments. PCM’s have the ability to transform from one state to another due to variations within a certain range of temperatures. In general these changes are caused by absorbing the heat from the environment and back into system via reverse cooling process. Therefore, PCMs are often incorporated in fibres or coating and membranes for the application in smart T-regulated textiles with thermal energy storage properties.
Bifunctional microcapsules based on a PCM core and magnet/silica hybrid shell for EMI shielding textiles are developed through a Pickering emulsification technology (emulsion stabilized by solid particles such as colloid silica) combined with interfacial polycondensation. The aim is to develop a novel inorganic encapsulation technology of bifunctional PCM microcapsules combining temperature regulation and EMI shielding for special exposure suits.

Another approach is the designing and the development of functional textile with new bifunctional microcapsules based on PCM core and TiO₂ shell in order to obtain not only heat-storable function but at the same time having the capability of anti-bacteria. Furthermore the TiO₂ wall will contribute to physical strength, and high thermal conductivity.

Another possibility is PCM’s with a calcite CaCO₃ shell with high rigidity. The CaCO₃ wall can provide good protection for the packaged PCM’s. The inorganic-packed PCM’s show enhanced durability and processability for the application of thermo-regulating textiles.

3.5. Preventing, alarming and Interactive textile

Smart and interactive fabrics (SFIT) are capable of sensing, actuating, storing power and/or communication. R&D dealing with wearable textile for personal systems such as health monitoring, protection, safety has increased strongly during the last decade. Indeed, a large body of work has been undertaken in flexible sensors, wearable electronics and the miniaturisation of sensors and actuators, leading to significant progress on interactive textiles supported by flexible electronics.

a) Thermochromics for preventive and alarming functions

The emphasis of recently finished research projects (Sensortex – IWT and ChromTex – Crosstexnet) at TO2C-lab project was on chemical sensoric functionalities that do not necessitate external components and power sources. It was the scope of both projects to engineer chromic indicators (thermo-, photo chormics), to study the required host-systems and application technologies for yarns and elastic narrow fabrics, to define innovative new applications of chromic functionalities, and to create business models for these applications. We succeeded in the development of microcapsulated thermochromics with T-change < 1°C and in a broad T-range (-15° ≤ T ≤ 60 °C). These thermochromics can be used as a visible sensor system, triggering the change of external stimuli.

Another approach is dealing with wearable textile for personal systems such as health monitoring, alarm and interactive textile (SFIT) are capable of sensing, actuating, storing power and/or communication, leading to significant progress on interactive textiles supported by flexible electronics.

a) Textile for early medical warning

Thermochromic garments for early medical warning. Body temperature is used in medicine as an index of health. Elevated human body temperature can be a sign of various conditions indicating fever (global temperature raise), or infection (local temperature raise). Thermochromic garments could provide continuous indications of the body temperature eithers as a whole (i.e. underwear, shirts) or locally (i.e. sock).

b) Textile indicating allergic bronchitis
Another possibility for these thermochromics is to develop sensoric textile indicating allergic bronchitis of kids caused by sweating. This illness is set by many causes such as smoke, odor, chemical odors, atmospheric pollution and sweating except infections. The coughing fit, which is increased by sweating is widespread. Measuring kids sweat level and checking their situation afar is therefore very important. Garments treated with thermochromics whose color can change accurately in function of the sweating level of the kids result in the preventive control of kids and as a consequence in preventing the coughing of the kids, which is developed by sweating.

3.6. Slimming fabrics
Slimming fabrics. There are miscellaneous textile applications to help slimming such as the use of microcapsules not always however with the desired durable effects. Water-resistant slimming fabrics are now developed and deigned based on a natural mineral known as tourmaline crystals (Tourmaline is a semiprecious gemstone). Moreover, these fabrics could have a healing effect. Infrared radiation that tourmaline begins to emit the heat from the body, negative ions, magnetic field, penetrate into deep layers of the skin, destroying free radicals and other harmful substances. Commercial tourmaline belts are already on the market. the producer claim that the belts can rebuild and supply the human biofield and reduces harmful effects such as pain in the muscles, stress, fatigue, leg swelling etc.

4. Summary
This article hopefully has taken you on a small fascinating tour dealing with smart clothing. Maybe this article will be a launching pad for some new ideas and concepts in material and product design. Together with new eco-technologies such as atmospheric plasma, digital technologies, UV … it is clear that engineering protective, casual and performance products can result in new smart clothing fulfilling the customers requirements and needs of multi functionality within the spectrum of protection, performance, comfort, injury-preventive, aesthetic and many other properties. It can maintain or even create business activities for small and large enterprises.

It is clear: developments will be come more and more from the research lab as the result of a symbiotic teamwork consisting in textile technologist, designers, garments engineers, biologist, media experts and many others. A lot of new developments is possible: we don’t even have scratch of the surface of future-oriented developments in textiles.

will be continued...

Prof. Dr. Marc Van Parys
Research Lab TO2C
University College Gent
Belgium
Info&unitex.be