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Sustainable design approach for technical textiles

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Abstract
Smart and interactive textiles are fibrous structures that are capable of sensing, actuating, generating/storing power and/or communicating. Research and development towards wearable textile-based personal systems allowing e.g. health monitoring**,** protection & safety, and healthy lifestyle gained strong interest during the last 10 years. The term 'smart' has been used to describe functional textiles with engineered properties. This includes anything from curtains that light up in the dark to odorless socks or concrete reinforcements. Smart textile and integrated wearable electronics can be used for sportswear, industrial purpose, automotive & entertainment applications, healthcare & safety, military, public sectors, and new developments in smart textiles. New, sophisticated smart textiles, will be able to sense, transmit signals, process data or control the behavior of the textile. Various new materials will be introduced such as shape memory materials, to adjust the texture of fabrics depending on temperature change or phase change materials, to create a cooling effect or store excess heat. As the technology is becoming more flexible these could ultimately be integrated into a common textile substrate-our clothes, becoming truly portable devices. Smart textiles should be introduced as a potential development to make the textile world more sustainable. To improve the product's lifetime, it is important that the product represents more than its functionality, which can be accomplished through its design. This paper discusses the difference between ordinary sustainable methods based on saving energy and resources and methods that tackle excessive consumption, such as user involved design, closing the loop, minimizing waste by re-collection, convertible smart textiles, eliminating waste, etc. to enhance product durability. To improve the product's lifetime, it is important that the product represents more than its functionality, which can be accomplished through its design.

Keywords: Smart textiles, technical, electronic, sustainable, longevity

1. Introduction
The original function of textiles was to protect man from extreme climates, for modesty, for protection etc. But later on, aesthetic aspects also came to play a role in clothing. More recently a new generation of textiles has risen of smart and interactive textiles. Smart Textiles also known as Technical textiles or Interactive textiles are active textile materials that have sensing and actuation properties. Their potential is enormous and one could think of smart clothing as a textiles that makes us feel comfortable at all times, during any activity and in any environmental conditions, a suit that protects and monitors, that warns in case of danger and also helps to treat diseases and injuries, aids in patient health monitoring through sensor embedded garments, helps to improve athletic performance both by analyzing sensor data and adapting to changing conditions which provides environmental sensing and communication technologies for military defense and other security personals.
The smart textile can sense and react to environmental conditions or stimuli from mechanical, thermal, chemical, electrical, magnetic or other sources. Smart textiles must possess 3 components. i.e. sensors, actuators and controlling units. The sensor provides nerve system to detect signals. Smart textiles are a combination of textile and electronics. Wearable technology is also gaining popularity as smart textiles become a highlighted conversation in the fashion industry. With wearable technology, consumers can achieve anything from a stable body climate to monitoring their heart rates. Although the development of these smart, breathable and cutting-edge textiles promises a shift away from the conventional and chemically-ridden fashion industry, there are many challenges.

Smart Material & Its Classification

“Smart material" is a generic term for a material that in some way reacts to its environment. Smart materials can be classified in many different ways, for example depending on their transforming function: property change capability, energy change capability, discrete size/location or reversibility. Smart materials can also be classified depending on their behavior and function as passive smart, active smart or very smart. Another way of classifying them is to look at the role they could have in a smart structure, as sensors or actuators.

1. Passive smart materials can only sense the environmental conditions or stimuli; they are sensors
2. Active smart materials will sense and react to the condition or stimuli, besides the sensor function, they also have actuation characteristics.
3. Very smart materials can sense, react and adapt themselves accordingly;
4. An even higher level of intelligence can be achieved from those intelligent materials and structures capable of responding or activated to perform a function in a manual or pre-programmed manner.

The materials of our surroundings are being “intellectualized”. These include conductive metallic yarns like silver, stainless steel, carbon fiber textile yarns with electrical properties. Yarns containing conductive fibers like stainless steel mix with natural synthetic fibers, polymeric or carbon coated threads Conductive yarn, conductive rubber, and conductive ink have been developed into sensors or used as an interconnection substrate. These materials can interact, communicate and sense. Other materials involve Metal Fibers, Coating with Nano-Particles, Organic Semiconductors, Shape Memory Materials, Chromic Materials, Conductive Inks, Inherently Conductive Polymers, Optical Fibers.

2. Methodology

Types of Sensors

1. Blood Pressure Measuring Sensors:
2. Body Temperature Measuring Sensors
3. Pulse Rate Measuring Sensors

- **Interconnection & Power Supply**

When two pieces of E-textiles have to be interconnected both these issues have to be considered simultaneously. Thus there is need to develop interconnection between electronic components and textile. In power supply technologies typically batteries provide the electrical power for activating components in an electronic textile. In recent years, batteries have not only become smaller and more powerful water resistant and lower cost. One type is fabricated by screen printing silver oxide based paste on a substrate to yield battery only 120 microns thick, solar energy and energy created by the human body are also being studied as sources of electrical power for electronic components. Two of the most known approaches to develop new power supply technologies, are lithium polymer battery and micro fuel cells. Sunlight, body temperature and body motion are alternative energy sources on the body that can be transformed into electrical energy. Thin film solar cells can be made on flexible surface technology has also been adapted to fibre form. The efficiency of these alternative energy sources needs to be improved.

Fig 1: Thin film solar cells in cloth

Applications of Smart and Interactive Textiles in Various Fields

Smart textiles can be broken into two different categories: Aesthetic and Performance Enhancing. Aesthetic examples include everything from fabrics that light up to fabrics that can change color. Some of these fabrics gather energy from the environment by harnessing vibrations, sound or heat, reacting to this input. Then there are performance enhancing smart textiles, which will have a huge impact on the athletic, extreme sports and military industries. There are fabrics that help regulate body temperature, reduce wind resistance and control muscle vibration-all of which help improve athletic performance. Other fabrics have been developed for protective clothing to guard against extreme environmental hazards like radiation and the effects of space travel. The health and beauty industry is also taking advantage of these innovations, which range from drug-releasing medical textiles, to fabric with moisturizer, perfume, and anti-aging properties.

Fig 2: shirt for measuring rehabilitation

Fashion and Entertainment

Club wear that reacts to movement, heat and light is one example of such kind. They include garments with panels that illuminate when the dancer moves, or clothing that contain fibre optics woven and integrated into the fabric.

The development of high-tech advanced textiles for initial high-value applications such as extreme sports will eventually find its way into street fashion, with designers employing their creativity to use these emerging materials in new ways. As the technology is becoming more flexible MP3 players, laptops, mobile phones and digital cameras could ultimately be integrated into a common textile substrate-our clothes, becoming truly portable devices. While technology may be hidden through invisible coatings and advanced fibers, it can also be used to dramatically change the appearance of the textile, giving new and dazzling effects. Light emitting textiles are finding their way onto the haute couture catwalks, suggesting a future trend in technical garments. Gloves that contain heaters, or built in LED's emitting light so that a cyclist can be seen in the dark.

Smart textiles are fabrics that have been developed with new technologies that provide added value to the wearer. What makes smart fabrics revolutionary is that they have the ability to do many things that traditional fabrics cannot, including communicate, transform, conduct energy and even grow.

Fig 3: Dresses made from photo luminescent thread and embedded eye tracking technology from Ying Gao

3. Results & Discussion

Advantages for Sustainability

Smart textiles are often introduced as a potential development to make the textile world more sustainable. The driving forces behind these claims are based on the following.

Textile care: Within the lifespan of a piece of clothing, washing, drying and ironing make up the largest consumption of energy and water. (Fletcher and Goggin, 2001).

Cleaning: Ideally textile materials should be self- cleaning or stain repellent to reduce the necessary washing cycles. New nano materials, such as Nano-Sphere (Schoeller, 2011), have been developed with a special finish that repels water and dirt (Lai, 2003). Unfortunately, users wash their clothes not only because they are dirty but just as much to get the fresh feeling of a newly laundered item (Black, 2008) [6]. Therefore, this new material would only be effective if consumers change their habits and refrain from washing to refresh their clothing.

Textile durability: The lifecycle of clothing is relatively short. One of the causes is the poor quality of textile materials, which is an effect of mass production in combination with price competition. The development of self-repairing textiles is able to counteract this movement and produce textiles that last longer. However, such developments would only be possible if people were willing to pay more for their clothing and change their collection less often.

Feel good fabrics: Our clothing has a unique function, which is to make us feel good about ourselves. Comfort and well-being are important drivers for happiness.

The claims above are focused on the user side of the smart textile products. These are just as important as the sustainable aim to create smart textiles, which are efficient and recyclable. There is nothing more wasteful than a product that does not work or does not meet the expectations of the user. In manufacturing, products that last longer does not necessarily pose a threat to a healthy economy. Reducing the need for rapid product replacement leads to new services, possibilities to upgrade and above all, it allows products to become prone to aesthetic aging which will ultimately attract loyal customers (Hinte, 1997). According to Jonathan Chapman (2009), if we limit ourselves to the physical durability, we will simply end up with durable waste. To improve the product's lifetime, it is important that the product represents more than its functionality, which can be accomplished through its design. Design provides meaning; it offers the possibility to attach oneself to a product. Products that live longer cause a reduction in sales volume and minimize the option for product innovation. With the desire of consumers to pay the least possible price for the product, has led to over- consumption and waste (Hethorn and Ulasewicz, 2008).

Improving durability

It is very difficult to compare products based on sustainable criteria such as energy consumption, material usage, reusability or recyclability. Even for products of the same category, it is difficult to judge the environmental impact, because most sustainable criteria are complex and may not produce comparable results (Shedroff, 2009). Comparisons are much easier when the product lifetime is considered. Products that last a long time are more likely to be the best sustainable choice, with the exception of products that consume a substantial amount of energy during usage, such as cars, fridges or light bulbs (Hinte, 1997). The lifetime of these energy hungry products may be challenged when they become less efficient in comparison with new technologies.

Improving the sustainability of smart textiles

In general, extending the product lifetime is an important approach toward reducing the environmental burden. However, if product life is such an important issue, why are products replaced at ever increasing rates? There are several factors that influence the end of a product's life (Walker, 2006 [4]; Shedroff, 2009). These factors vary from disposability, wear, non-reparability, functional obsolescence, technological obsolescence and aesthetic (psychological) obsolescence (Ossevoort, 2010). Most of these are directly linked to the product's physicality with the exception of aesthetic obsolescence. The latter is a decisive factor for textile materials. Traditionally, designers work from their own experience, observe problems, and generate an accepted solution. The challenge lies within accepting the different points of view of the user. After all, a good designer interprets user needs into a desirable solution. User involved design is an important topic in the design community these days. It is more diverse than a user test at the end of the product development stage. The latest addition in user involved design is 'crowd funding', in which design initiatives are presented on the internet to create a group of followers, who make a pledge to purchase the product. Only if a design initiative gets enough followers, will it be produced and distributed.

Smart textiles do not necessary imply a less sustainable option to ordinary textiles, as long as the product offers better user value, user attachment and longevity.

Smart textiles are the result of joint research activities in the field of nanotechnology, microelectronics, information technology and textile technology. It is the interdisciplinary nature that makes smart textiles one of the most promising areas of innovation.

The sustainability paradox: There are serious doubts about the sustainability of smart textiles. It is not strange to see where this distrust originates; both the textile and the microelectronic industry do not have the best records on sustainability. The textile industry, as one of the oldest industries, has introduced many environmental and social problems. The most important raw materials, cotton and polyester, are responsible for severe environmental problems due to the excessive use of water, energy, insecticides, and chemical treatments and improper waste disposal after use. As part of the clothing industry, the textile industry has inspired unbridled consumerism, which leaves no space for durable products. The microelectronic industry is responsible for polluting our environment with heavy metals and toxic chemical compounds. (Allwood *et al.* 2006; Köhler *et al.* 2011) [1]

Creating a sustainable future: Although the word 'sustainable', derived from Latin sustinere, tenere, to hold (*Collins English Dictionary*, 2009) may imply a rigid endurable state, it actually stands for a repetitive cycle, which can only be achieved by looking forward. According to the Brundtland Commission (1987), sustainable developments meet the needs of the present, without compromising the ability of future generations to meet their own needs.

Recycling, a necessity: Textile recycling- In general, textiles are well suited to recycling, although the quality of the fibres limits the field of application for recycled materials to insulation, protection, cleaning or filling materials. Even though this process involves degrading (downcycling), it gives 95% of all textiles and clothes (which are handed in for recycling) a second life. Despite the possibility to recycle, the majority (85% in the UK) of textiles and clothes end up in landfill sites, partly due to the fact that it is all too easy for consumers to throw unwanted products in a rubbish bin (Textile Recycling Association, 1999; Allwood *et al*, 2006) [5, 1]. This was very different about 200 years ago, when the demand for raw materials for the textile industry grew beyond its supply. The open market economy has pushed the availability of cheap raw materials to unsustainable levels, which makes recycling a less attractive option. Besides, the diversity of materials and their blending compositions is so large that only experienced personnel are able to separate textiles by their material composition. These difficulties make textile recycling both difficult and costly. Another problem is that currently about 54% of textiles are of synthetic origin (Gherzi Consultants, 2011), which is hard to break down for re- spinning. The separation process of synthetics could potentially be improved through electrostatic and chemical separation, but the two processes are expensive and might not be feasible on a large scale (Allwood *et al*, 2006) [1]. Smart textiles, with their multiple material compositions, will certainly make the process of recycling more complicated.

Sustainable production of smart textiles

It is in the interest of any company to minimize the environmental impact of production by reducing waste, energy consumption and material usage. These measurements of efficiency do not only support the environment but also have a positive impact on business revenue. Through a lifecycle analysis (LCA), an intensive analysis of the consumption of energy and materials before, during and after production, companies can strive for increased efficiency. A practical LCA method to measure the eco- efficiency is the MIPS method (Material Input per Service unit), which takes into account the materials required to produce a product or service (Wuppertal Institute, 2012). Although efficiency is a way forward, a company can only reach truly sustainable production if it assumes responsibility for the resources to the end user, from the collection of raw materials to the end life of a product. This may be problematic for smart- textile producers, since their products are intermediate goods, disconnected from the end user. Therefore, the sustainability of smart- textile products depends on the sustainability of its various components.

1. **Closing the loop:** Most products are destined to become waste at the end of their lives, a process in which valuable resources are lost forever. It is of benefit to the environment to reduce the amount of waste; however, true sustainable production means closing the loop of a product's lifecycle and eliminating the concept of waste.
2. **Minimizing waste by Re-collection:** Recollection schemes are a good way to minimize waste. They will become common practice since the European directive for Waste Electrical and Electronic Equipment (WEEE Directive, 2003) has enforced manufactures to re- collect electrical and electronic equipment for disassembly. However, this directive does not explicitly address smart textiles. As long as smart textiles are a niche market for professional and medical clothing applications, they may find their way back to the original manufacturer, but this will change when smart textiles become part of the mass market of today's clothing industry. Ruled by the concept of fashion, smart- textile products will become subject to the notion of change, which generally produces waste (Hethorn and Ulasewicz, 2008).
3. **Eliminating waste:** Most products endure a lifetime from 'cradle to grave', in which their original material is lost indefinitely. McDonnell and Braungart (2002) initiated an approach to carry products from cradle- to- cradle, thereby elimination waste. They observed that nature lacks the concept of waste; any remainder from a natural process serves as a nutrient. Biological nutrients are of natural origin and can be composted after use. Technical nutrients may be inorganic or synthetic materials, as long as they are non- toxic, have no negative effects on the natural environment and can be recycled indefinitely, thereby staying out of the natural environment. Since smart- textile materials are mostly of synthetic origin, the challenge is to exclude any toxic materials and create smart materials, which can be recycled indefinitely.
4. **Convertible Smart textile recycling:** The ability to recycle smart- textile products depends on the materials used and the level of integration between the textile and technological components (Mecheels *et al.* 2004; Tang and Stylios, 2006; Cho *et al.* 2010). The lowest level of integration between textile and technology is a pocket, designed to contain a piece of technology. A well- known example is the watch pocket on a pair of Levi's jeans introduced in 1903.

The logical next step is using the textile surface to mount electronic hardware in an ordinary way: stitched, attached with Velcro, buttoned, zipped, clipped or pinned. The autonomous sensor button, an independent senor node is a good example of a smart object built inside the button of a shirt. It can be stitched onto a textile surface, but should be removed when the product is disposed of. Not removing the electronic hardware will almost certainly disturb the recycling processes of the textile materials (Wäger *et al.* 2010; Köhler *et al.* 2011). Small RFID tags have already caused problems in established recycling processes of non- electronic goods. Even when removed, electronic hardware is very difficult to recycle. An average electronic device may contain as many as 40 different materials in very small quantities. Although most harmful materials have been restricted in a European directive for the Restriction of Hazardous Substances (RoHS), the most common way of recycling, shredding products into smaller entities, does not separate the basic materials. Experiences with the disposal of contemporary electronic waste (e-waste) give reason to expect severe environmental and social impacts worldwide (Köhler, 2008) [2]. Whilst, in theory, the electronic hardware can be removed and reused in future applications, it does not count for the conductive textile materials, which are infinitesimal metal depositions, such as silver, gold, copper and nickel on a polyamide or nylon yarn. The layer of these metal depositions is too thin to be recycled in a mechanical way.

The notion of product- smartness has recently shifted toward more active and 'intelligent' functions. Recent research uncovered that textiles can lose more than 1900 fibres per washed item (Browne *et al.* 2012). As the human population grows and people use more synthetic textiles, the environmental problems become more eminent. This is certainly the case with the introduction of nanoparticles in textile materials. The behaviour of the nanoparticles of any given material may be very different from the actual material properties. For instance, in its natural form, gold is famously inert. However, at a particle size of 2 to 5 nm, gold becomes highly reactive. The chemical composition of these two materials is identical:

It is the different physical size of bulk materials and nanoparticles that accounts for their very different chemical properties (RCEP, 2008). The introduction of engineered nanomaterials into textile products will ultimately be followed up by a large- scale production. With this future vision in mind, risk assessment is extremely important before any unintended release of engineered nano materials might harm human and environmental health (European Commission, 2011; Som *et al.* 2011). It emphasizes that smart=textile developers have to make design decisions under conditions of uncertainty for which it is important to understand where we have choices and where we do not (Allenby, 2009).

Other additional methods to help the smart textiles be more sustainable are: Zero Waste pattern, Construction variations & Smart Tailoring, Design for Disassembly, Design for Longevity etc.

Making smart-textile products truly sustainable is not a viable aim, nevertheless it is important to do whatever is necessary to reduce the environmental burden. For smart textiles, like most electronic products, the best results can be obtained by creating user commitment and a closed loop recycling system.

We need to think about the entire life cycle which will close the loops and we need to think about what textiles can do for designers and consumers.

Smart textiles could be a greener solution for many aspects of the fashion industry, including outerwear. With designers, affiliates and consumers concerned about animal welfare, smart textiles could replace jackets that are typically created with animal-sourced materials. By using these digitally-enabled materials, the fashion industry could further its commitment to sustainability. Making smart- textile products truly sustainable is not a viable aim, nevertheless it is important to do whatever is necessary to reduce the environmental burden. For smart textiles, like most electronic products, the best results can be obtained by creating user commitment and a closed loop recycling system.

We need to think about the entire life cycle which will close the loops and what textiles can do for designers and consumers.

4. Conclusion

The world is looking for solutions to major sustainability challenges that developed with the consumer culture. Among other fields and aspects, the way people design, produce, wear and dispose clothes in the traditional cradle-to-grave model has gained interest. The garment life cycle is continuously innovated from different angles. Examples of sustainable materials, business models and ways of thinking about clothing appear in research and practice both. Independently, the fashion scene gets more and more curious about the possibilities of using electronics and digital properties in clothing, also known as fashion technology, wearable technology and smart textiles. The marriage of the two worlds, that closely influences many people, carries potential concerns and opportunities. Textile manufacturing was one of the drivers of the development of technology from pre-industrial craftsmanship to today's industrialized consumer culture. In this work, crafts and craftsmanship are taken as an example of sustainable living. The traditional crafts and sustainability are discussed in the context of the developing field of smart textile services. This is the tip of the iceberg, and we will only start to see more and more companies and designers emerge who will create amazingly innovative smart textiles and develop technology that will undoubtedly change the way the live, forever. Within Smart Textiles we prioritize the environment and work active to integrate this in all parts of our activity. For us, sustainability, durability, quality and functionality are also important factors for sustainable development. New sustainable solutions for the textile industry, with regard to raw materials, pre-treatment, production and use, are an expressed need of society. We see sustainability from an environmental perspective which is connected to long-term use.

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