14
Improving the sustainability of smart textiles

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Abstract: Smart textiles do not necessarily imply a less sustainable option to ordinary textiles, as long as the product offers better user value, user attachment and longevity. This chapter discusses the difference between ordinary sustainable methods based on saving energy and resources and methods that tackle excessive consumption, such as user involved design to enhance product durability. It discusses the theoretical model of user involved design through a practical example of the development of a smart lightweight tracking tent and concludes with a set of general guidelines for developing sustainable smart-textile products.

Key words: user involved design; smart-textile durability; smart-textile recycling; sustainable design guidelines.

14.1 Introduction

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 development of smart textiles is of vital importance for the textile industry. Due to globalisation, most traditional textile companies have lost their core activities to low wage countries. Smaller companies have merged into massive industries, which try to survive in a highly-competitive environment. Despite these mergers, Chinese companies have taken the lead, since they are able to offer an attractive low priced 'one-stop textile marketplace.' At the moment, more than a quarter of the production of textiles and clothing is in China, a market share that will increase along with China's growing domestic market (Allwood *et al.*, 2006). In order to remain competitive, smaller traditional textile companies have had to specialise, a process in which smart textiles offer a promising way in which to enter a high tech niche (*Economist*, 2005). The development of smart textiles involves necessary improvements in order to remain competitive (Keenan *et al.*, 2004):

- new production technologies (process technologies, automation);
- new information and communication technologies (ICT);
- new materials and products (multi-functional textiles and garments);
- innovation and research and development (R&D).

In order to realise the necessary technological developments, many companies have increased investment, which has put a corresponding increase on

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the industry's financial burden. We are reaching a point in which smart textiles should deliver their promise. Innovation for the sake of change is not a sustainable practice.

14.1.1 The sustainability paradox

There are serious doubts about the sustainability of smart textiles (Allwood *et al.*, 2006; Köhler *et al.*, 2011). 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 has a similar reputation. It is responsible for polluting our environment with heavy metals and toxic chemical compounds. For the production of components, there is a great need for rare earth metals and minerals (i.e. coltan, gallium or indium), which has lead to many international and national conflicts (SVTC, 2004). The industry has created a highly digital and automated world, bringing forth social changes, which have not always been received positively.

14.1.2 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. In order to be sustainable, the industry should never lose sight of its future aim. There are plenty of examples from the past in which a mindless search for innovation has led to environmental catastrophes.

One example from the textile industry is the development of aniline dyes. Up until the nineteenth century, textile dyes were a rare costly material, mostly extracted from minerals and plants. Their natural origin implied an uncertainty, since quality and supply depended on natural parameters. With the mechanisation of the textile industry, natural dyes became an unreliable source, which called for an alternative. The answer came in 1856, when an 18-year-old chemistry student named William Henry Perkin (1838–1907) accidentally created the first aniline dye distilled from coal, named *Paris* or *Emerald Green*. The common availability of the raw material and the brightness of its colour were the base for its success

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and soon many aniline dyes where developed. However, nobody wanted to admit, despite common suspicion, to the poisonous nature of the green dye, due to its arsenic compound; the wheel of progress had run too fast to be slowed down. Arsenic dyes remained in use for over 60 years, causing many casualties in our society (Chase and Scott, 2010).

Also, today, we encounter examples in which the innovation potential blinds us from future pitfalls. The development of smart phones and tablet PCs has been highly competitive. In a bid to be the first on the market, producers have adopted indium tin oxide (ITO), a sintered mixture of indium (In_2O_3) and tin oxide (SnO_2), as a transparent conductive layer for their capacitive touch-screen panels (Grossman, 2007). There are not many alternatives to ITO, particularly given its ability to function in humid conditions. As a consequence, the popularity of smart phones and tablet PCs has created a worldwide shortage of indium deposits. Currently, research is being carried out to find prospective replacements such as carbon nanotube conductive coatings (Kaempgen *et al.*, 2005). If no suitable alternative is found, recycling will become a necessity in order to avoid a severe material shortage by the year 2040, but that might prove to be too difficult to be a viable option (Kapilevich *et al.*, 2009).

To make matters worse, ITO has caused interstitial pulmonary diseases amongst those working with the material (Chonan *et al.*, 2007), whilst further research has proven ITO to be a new toxicological entity (Lison *et al.*, 2009). There are still many uncertainties regarding the health and environmental risk of any nanomaterial. Caution is in place, certainly for textile applications at large scale and volume. Let us learn from these mistakes and aim for a smart textile future, where technological developments improve our health, comfort and well-being, without interfering with our natural environment.

14.2 Sustainable production of smart textiles

It is in the interest of any company to minimise 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. Like other textile producers, they import

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yarn and outsource textile treatments; their end product is one of the many supply chains available for smart product concepts, amongst others such as textile fasteners, electronic components, sensors, batteries or displays. Therefore, the sustainability of smart-textile products depends on the sustainability of its various components.

14.2.1 Transparency

Where do the raw materials come from? What happens during the production process and who takes responsibility at the end of a product's lifecycle? Each supplier is liable for its contribution and has to be open about the environmental impact, early examples of which can be seen in the car industry. Car manufacturers demand certain liabilities from their suppliers in terms of packaging materials; otherwise they will be sent back. As a result, the car industry has increased the need for reusable packaging material.

Despite these liability schemes, complex products lack the transparency needed to offer truly sustainable production (Shedroff, 2009). In our globalised, price-driven and competitive economy, many material resources remain deliberately unidentified. This lack of transparency can only change through the enactment of new laws. However, real changes can only come from consumers' demands and the sustainability policies of the companies.

14.2.2 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.

Minimising waste

Recollection schemes are a good way to minimise waste. They will become common practice since the European directive for Waste Electrical and Electronic Equipment (WEEE Directive, 2003) has enforced manufacturers to re-collect electrical and electronic equipment for disassembly. However, this directive does not explicitly address smart textiles (Köhler *et al.*, 2011). 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).

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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 eliminating waste. They observed that nature lacks the concept of waste; any remainder from a natural process serves as a nutrient. In other words, waste equals food. The cradle-to-cradle approach makes a clear separation between technical and biological nutrients. 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.

14.3 Recycling, a necessity

14.3.1 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 (down-cycling), it gives 95% of all textiles and clothes (which are handed in for recycling) in the UK 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).

This was very different about 200 years ago, when the demand for raw materials for the textile industry grew beyond its supply. The shortage in wool initiated the development of the pulling process in 1815, which involves breaking down woollen textiles into their constituent fibres (shoddy), so that they can be re-spun into fresh thread (Cupit, 1996). Nowadays, the recycling industry for wool has almost disappeared. 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). Smart textiles, with their multiple

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material compositions, will certainly make the process of recycling more complicated.

14.3.2 Smart textile recycling

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 odour-free socks or concrete reinforcements. 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 (Fig. 14.1).

14.1 Watch-pocket on a pair of Levi's jeans.

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14.2 Smart object built inside the button of a shirt.

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 (Bharatula *et al.*, 2004) is a good example of a smart object built inside the button of a shirt (Fig. 14.2). 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).

Further integration of electronic hardware into textiles has lead to the development of conductive textile materials (Table 14.1). 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

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Table 14.1 Overview of conductive (electric, magnetic and optical) textile materials

Material	Application	Producer
Metals:		
Conductive black polyester (Ni), Cu, Ni – Sn	Self cleaning, antibacterial and UV protection	http://www.shguilian.com
Stainless steel threads	Magnetic wave shielding	http://www.bekaert.com
Silver plated fabric: (Ni) Cu, (Ni), Ag	Conductive fabric, EMR shielding, wound healing, odour control or anti-microbial	http://www.x-staticfiber.com
Gold Plated fabric: (Ni), Cu, (Ni), Au	Conductive fabric, EMR shielding	http://ajinelectron.co.kr
Electro Magnetic Fabrics: (Ni), Cu, Ni – Co or (Ni), Cu, Ni – Fe		http://www.chinabaicheng.com
Shape Memory Alloys Cu – Zn – Al – Ni and Ni –Ti	Deformable fabrics, ergonomic support, thermo regulation suits	http://www.dynalloy.com
Polymers:		
Polyaniline (PANI)	Microwave and Radar Absorption, Electrostatic Discharge, Resistive or Microwave Heating and Pressure Sensors	http://www.eeonyx.com http://www.fibrontech.com
Polypyrrole (PPy)		http://www.eeonyx.com http://www.fibrontech.com
Poly(3,4-ethylenedioxythiophene (PEDOT)	Conductive coating for Electro Luminescent Panels and Antistatic agent	http://www.heraeus.com http://www.agfa.com
Shape memory Polymers (PU, PET and PEO)	Deformable fabrics, ergonomic support, thermo regulation suits	Laschuk and Souto (2008)
Carbon nanotubes	Conductive coating	http://nanoshel.com
Carbon fibres	Durable clothing, improved heat absorbency	http://nanoshel.com
Optical fibres (PMMA and PS) or silica		http://www.lumigram.com http://www.starscape.co.uk

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way. According to McDonough and Braungart (2002), they should be classified as monstrous hybrids, material amalgamations that make recycling and cradle-to-cradle impossible.

The notion of product-smartness has recently shifted toward more active and ‘intelligent’ functions (Laperre, 2010). New, sophisticated smart textiles, will be able to sense, transmit signals, process data or control the behaviour 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. Although the improved efficiency and functionality of novel materials can bring environmental benefits, the risk of introducing these new materials into our waste stream, and ultimately our environments, is not well enough understood.

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 nanomaterials might harm human and environmental health (European Commission, 2011; Som *et al.*, 2011). It emphasises 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).

14.4 Product durability

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 textile care, textile durability and feel good fabrics.

- 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).

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Cleaning: Ideally textile materials should be self-cleaning or stain repellent to reduce the necessary washing cycles. New nanomaterials, 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). Therefore, this new material would only be effective if consumers change their habits and refrain from washing to refresh their clothing.

Ironing: Another approach is a new textile finish, which eliminates wrinkles, such as Nano-Tex (Brutten, 2011). Here we have to take into account that ironing is a formal habit. We might question the need for ironing as Dame Vivienne Westwood advocates.

- 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. In general, smart clothing can create a positive feeling to which the design has a central role (Black, 2008).

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. So the first question we need to ask is what is the added benefit of smart textiles and do these benefits weigh against the inevitable negative consequences for our environment?

In reality, 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 ageing which will ultimately attract loyal customers (Hinte, 1997). Whilst improving the physical quality is a precondition, creating durable products requires more. According to Jonathan Chapman (2009), if we limit ourselves to the physical durability, we will simply end up with durable waste.

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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.

Increased product durability implies a prolonged lifetime that is out of tune with universal economic principles of growth. Products that live longer cause a reduction in sales volume and minimise the option for product innovation. Yet in the area of sustainability, consumer ability to gather and apply the knowledge necessary to make the right choice is diminished by the established system of production. This system, coupled 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).

14.4.1 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.

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; 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.

14.4.2 User involved design

A way to challenge aesthetic obsolescence is by actively involving the user in the design process. 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.

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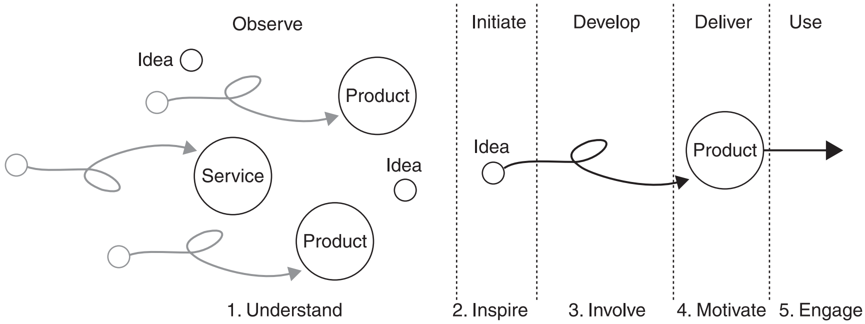
User involved design is an important topic in the design community these days. It is more diverse than a user test at the end of the product development stage. The latest addition in user involved design is 'crowd funding,' in which design initiatives are presented on the internet to create a group of followers, who make a pledge to purchase the product. Only if a design initiative gets enough followers, will it be produced and distributed.

Ideally users are involved in every stage of the design process, from the first observations to the final use inclusively. For each stage, there are several methods available to support meaning directed to the user involvement (Fig. 14.3).

For each of the key stages, I have identified a general approach:

- *Understand*: In this approach, the designer tries to understand the mechanism of creating value and to apply his/her knowledge (indirect), or a designer engages in observing the user and applies the outcome (direct).
- *Inspire*: Instead of generating a project from technological, market or business opportunities, the user will inspire a new idea.
- *Involve*: Rather than trying to understand, the designer invites the user to play an active role in the design process.
- *Motivate*: An object or service is not brought into completion until it is actually used. Motivate is an approach in which the designer deliberately creates space for the user to complete the design within its use.
- *Engage*: In this approach, the designer tries to establish a link between the user and object/service, which is durable over time.

For each approach, there are several design research methods available, which will be further explained through the example below.



14.3 User involvement in each stage of the design process.

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14.5 Sustainable design approach for a smart-textile product, an example

Products that satisfy the end user will have more chance to become a sustainable solution than products that support no particular value system. Unfortunately, users can only articulate product value in terms of existing products, which makes it difficult to predict the value of new products such as smart-textiles products.

In 2004, I was invited to the Hewlett Packard Labs in Bristol, to attend a workshop on smart-textile applications for teenagers. Amongst a group of researchers, we were convinced about the technological challenges that smart textiles offer. We presented some state-of-the-art working examples of high tech fashion to a group of teenagers. Afterwards, we ran a session with these teenagers from whom we expected to receive new ideas and insights. Instead, the outcome of the creative session was merely a direct translation of the technology we had presented onto their most desired pieces of clothing. Was there any reason we could have expected otherwise?

Of course, the user should be central within the design process; however, it is a classical mistake to expect the end user to be able to visualise their needs and wishes. The process of visualising needs and wishes into an inspiring new product concept remains the task of the designer. I will explain how the user can be involved in every stage of the design process with a short design example, a smart tent.

14.5.1 Initial design

Imagine the design of a tent, in which the upcoming smart-textile technologies offer potential for innovation. It is tempting to focus on new materials to increase the performance, such as weight reduction or the addition of new features, such as solar panels or thermo-electric materials (Hewitt *et al.*, 2012) to charge electric equipment. However, rather than asking the question, ‘How could we apply smart-textile technology to improve a tent?’ designers should ask: ‘How could we improve the pleasure of spending the night outside?’, which automatically calls for a deeper understanding of the end user.

Understanding

Of course, there are many types of tent, which provide different solutions for different users. There are tents for outside parties, families or single persons, tents to exclude mosquitoes, to shelter from the sun, or even tents within a hospital environment to protect patients from airborne infections. Let us focus in this example on a lightweight outdoor tracking tent for two people.

There are different reasons why one would buy a lightweight outdoor tracking tent, which also implies that there are various types of users or user profiles. Designers normally improvise a range of user profiles to challenge their design ideas.

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Unfortunately, most improvised user profiles are too shallow to spur new ideas; they remain a reflection of the designer's own cultural background (Shedroff, 2004).

Instead, try to map the whole range of possible user groups, which includes unintended or extreme users. In our tent example, one should not only look at people hiking with a rucksack but also observe people who would like to take a tent to shelter whilst fishing or people who visit an outdoor music festival. Unlike the average user, unintended and extreme users give the best ideas for user driven innovation.

Once it is clear who might be the end user(s) of the product, it is time to make things real. Understanding users means talking with them, giving them certain tasks and getting involved. Methods like individual interviews and rapid ethnography (Table 14.2) prove to be useful at this stage.

Inspire

Now we understand the variety of users, we could ask what they expect from their tent. However, asking such a direct question like: 'What do you expect from your tent?' would not produce a useful answer. People judge objects through their value(s). If the most important value for a tent is security, we should ask what users expect from a secure outdoor place.

Multiple values can be retrieved from the stories users tell about their product. Words such as saves time, clear, flexible, convenient or easy will indicate a certain value (Kelly and Littman, 2001). Next to rapid ethnography, methods such as cultural probes (Gaver *et al.*, 1999) and personifications (Table 14.2) are helpful to unleash user stories.

In our tent example, the product value could be described as: 'A portable personal space to enjoy the outside with a certain amount of comfort.' This description gives designers a good base to discover new ways to increase or add product value.

Involve

We know that users expect a tent to provide privacy and protection against cold, windy and wet circumstances. However, we may have picked up on user stories, which challenge these values. Some users may have experienced a lack of privacy due to light projections when using flashlight or due to the poor sound insulation of the tent fabric. Other users may have experienced a lack of comfort through the dark, hot and humid atmosphere inside the tent.

Methods like role-plays or designer games (Table 14.2) are useful at this stage to analyse the problems, synthesise solutions or discuss concept directions. For example, a particular story about a user who could not find his or her tent during an outdoor music festival may be the inspiration to create a tent with a tracking device or an audio/visual feedback like a car in a parking lot.

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Table 14.2 Methods for user involvement

Approach	Method	Further reading
1. Understanding	Individual interviews Direct observation Rapid ethnography	Burns (1989) Coleman (2007) Norman (2005) (http://jnd.org)
2. Inspire	Cultural probes Personifications User scenarios	Gaver *et al.* (1999) (http://www.gold.ac.uk) Ossevoort (2002) http://www.designcouncil.org.uk under: design methods Moggridge (2007)
3. Involve	Workshops Role-play Designer games Focus groups Think aloud protocols (TAP) Rapid prototyping	Laurel (2003) http://designgames.com.au/role-plays Flex and the Innovationlab (http://www.designgame.nl) http://www.designcouncil.org.uk under: design methods Dumas and Loring (2008) Brown (2009) http://designthinking.ideo.com
4. Motivate	User intervention Personalisation Co-creation	Verbeek and Slob (2006) van Hinte (1997) Winsor (2006)
5. Engage	Sustaining enjoyment Renewing experiences Multisensory product design Emotional design	Pieter Desmet (http://studiolab.ide.tudelft.nl) Brunner *et al.* (2009) Schifferstein and Hekkert (2008) Norman (2005)

A versatile outcome of stories, ideas and concepts can be narrowed down by the likelihood of finding a smart-textile solution. In our example, a tent surface is ideal for generating electricity, creating a self-regulating climate textile or a one-way see-through layer. A further selection of concepts could take place in close discussion with the actual users.

Motivate

Imagine the best-valued concept is a tent with a solar fabric roof, which provides an indirect low-level task light inside the tent (Fig. 14.4). The main reasons are that flashlights are much too focused, may blind the other person in the tent, challenge the privacy by casting shadows on the tent and are reliant on batteries that may run out. The light could be a simple panel of electroluminescent material or LEDs, which shine through the inside tent layer.

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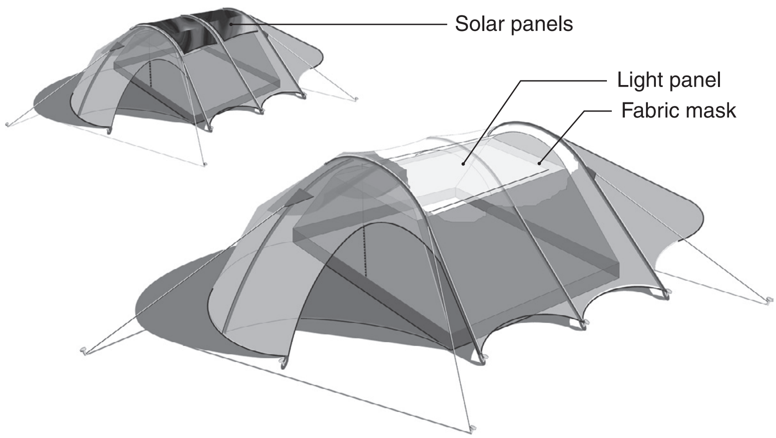

14.4 Simple panel of electroluminescent material or LEDs, which shines through the inside tent layer.

14.5 A fabric mask to resemble a starry night, plant-like motifs, and an indoor ceiling.

The designer could further improve the user-product relationship by motivating the user to intervene in the design. The light panel could shine through a fabric mask, which could be selected by the user to resemble a starry night, plant-like motifs, or an indoor ceiling (Fig. 14.5).

Engage

Engaging the user is especially important when the product is interactive. Interactive products behave in a particular way, which may become casual and uninspiring. Enjoyment and pleasure are important factors, which help to sustain the user-product relationship in order to increase the product durability.

14.5.2 Product development

Material

If weight were not an issue, the best sustainable tent material would be canvas (cotton), a renewable material, which lasts up to three times longer than a nylon.

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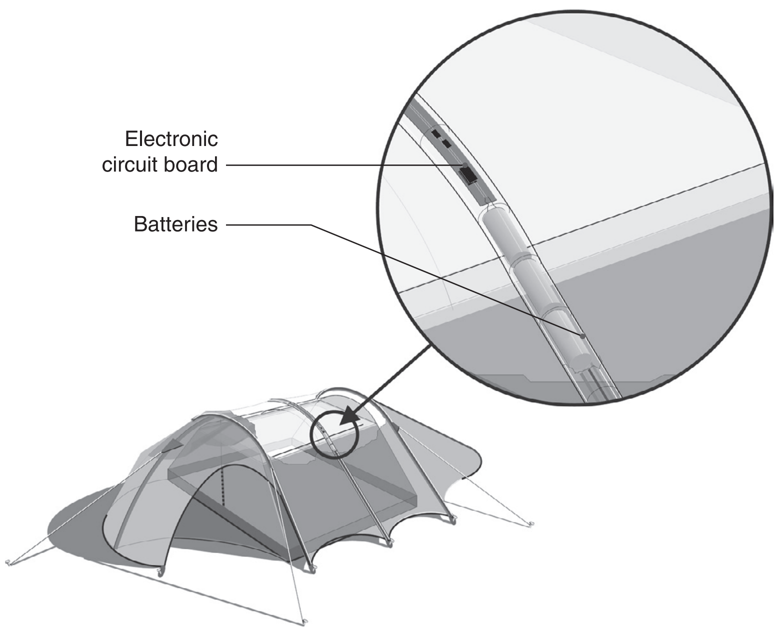
This poses the first challenge to a smart lightweight tent, the life expectancy of the material. Due to the UV exposure, a nylon tent only lasts about 12 to 30 weeks outdoors. Any smart materials utilised, such as solar panels and conductive thread, would ideally last no longer unless they could be separated and reused, which has some serious implications for the design.

A tent with the solar fabric roof would ideally have a detachable solar panel made from a more UV-resistant material such as polyester. Other important sustainable goals are using less material, mono-materials and renewable materials.

Production

The use of renewable resources or reusable parts and reduction of waste (or zero waste) are the best sustainable achievements in production. For lightweight products, such as tents, local manufacturing is not an issue.

Any electronic component, which exists as multiple material combinations, is ideally reused and should be kept separate from the normal waste disposal. The tent would include rechargeable batteries, which should be placed in a pocket or (well marked) inside a tent pole, to allow the user to separate them for recycling (Fig. 14.6).



14.6 The electronic hardware (circuit board and batteries) inside a tent pole to allow separation for recycling.

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14.6 General guidelines for the design of sustainable smart-textile products

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. I have created a general list of guidelines, which are important to consider for smart-textile products:

- *Simplicity*: Use smart textiles as much as possible as a carrier for simple and coarse sensors, such as resistive or capacitive sensors. Obtain precision through multiple sensors and extrapolation of data.
- *Surface*: Make use of the vast amount of surface textiles on offer. There is no need to create infinitesimal sensors and electronic components for textile surfaces.
- *Reliability*: Ensure reliability through multiple data paths, parallel lines and fail safe circuitry. Nothing can be more frustrating than a smart-textile product that fails to work properly.
- *Material*: Focus on a minimal use of materials, or even better mono-materials. There are some good examples of clothing, which consist of 100% polyester including Velcro™ connections and zippers, as well clothing made of 100% organic materials such as woollen jumpers.
- *Energy*: A sustainable future can only exist when it is independent of fossil fuels. Smart textiles in building façades, agricultural tarpaulins or outdoor clothing offer the possibility to harvest energy. Other applications, in which smart textiles may offer new possibilities, are membranes for reverse osmotic installations (Kim and Logan, 2011) or materials for energy storage.
- *Recycling*: Because electronic components contain (rare earth) metals, minerals and a plurality of other synthetic materials, they are best kept outside the normal waste stream. If possible, separate any (micro) controlling circuit from the smart-textile material or provide an easy way to separate them (design for disassembly).

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