Environmental sustainability of e-textile products approached by makers and manufacturers

Environmental Sustainable Approaches for E-textile Products for Makers and Manufacturers

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As electronics combined with textiles (e-textiles) move from the maker into production and the mass-market, questions concerning disposal and waste increasingly arise. Moreover, without standardization it is hard to manage the potential waste streams emerging after the product's life-cycle. The only guidelines for creating standards is Technical Report 16298 (2011) [1] by the European Committee of Standardization. This paper reports on two e-textile cases from the WEAR Sustain framework. The projects were developed collaboratively by makers, researchers and industry partners to shed light on issues of sustainability surrounding e-textiles.

The first, Closed Loop Smart Athleisure Fashion (CLSAF), measures the wearer's vital signs via printed and laminated sensors and focuses on the interactive fashion loop. It embraces the complexity that industrial settings tend to eliminate in products and processes. To keep stakeholders on board, it proposes a lease-service-system to replace conventional linear business models. The second, BETALight, is a wearable light space project that analyses the process from prototyping e-textile products through to industrial production. This project explores materials and processes in electronics and textiles at the level of component details. With industrial partners, the project tests and considers different production and recycling methods, and the best available materials and methods.

These two studies tackle a major issue in the manufactuing of e-textiles. It aims to provide a way of considering and evaluating the environmental impact of e-textiles based on collaborative practice.

Additional Key Words and Phrases: e-waste, e-textile, e-textile waste, environmental sustainability, smart textiles.

1 INTRODUCTION: SUSTAINABLE E-TEXTILES

The market for e-textiles is growing rapidly and, with companies like Google Inc. (USA), Interactive Wear AG (Germany), Textronics, Inc. (USA) and others [2] and a compound annual growth rate of 33.58% between 2015 and 2020, will likely exceed 4.7 billion US dollars by 2020. As the technologies reach the mass-market, questions arise about the sustainability of e-textile solutions. E-textile products carry a greater environmental impact risk than other purely textile or electronic products. It is necessary to understand both the electronics and textile industries as context for interdisciplinary collaboration that enables e-textile solutions.

1.1 Electronics

About 44.7 million tonnes of electronic waste (e-waste) was generated in 2016 and 52 million tonnes is expected by 2021 with an annual growth rate of 3–4% [3]. The United States is one of the largest producers of e-waste. As of 2015, however, 25 states and the District of Columbia, finally passed regional laws on discarded electronic items [4].

Kiddee et al. [5] report how 80% of old e-waste from developed countries is being exported to Lower Income Countries' (LICs) countries either for recycling or dumping. In LICs manual processes are done in residential properties resulting in significant contamination of soil, water and air.

1.2 Textiles

The production and use of textiles globally cause 3% of all greenhouse gas emissions [6]. In terms of the value and lifecycle of textile products, the textile sector is one of the most polluting industries in the world. In the EU alone, clothing and household textiles are the fourth most polluting product [7]. Several studies look at sustainability and consumption in the textile and apparel industry: Niinimäki and Hassi [8], present ways of rethinking and redesigning business in the textile and clothing fields through an overview of design strategies that exist in niche markets today. Niinimäki explained in her 2011 dissertation [9] the design process and its impact on the use phase of the product. Evaluating all details of design according to sustainability principles before manufacturing is essential.

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No precise data exists on where textile products go after consumers discard them. In the EU, most textile products end up in landfill or are burned, releasing methane into the atmosphere. The Joint Research Centre (JRC) report [7] and estimates by the Textile Recycling Association state that collection of disposed textiles for reuse or recycling in 2005 is between 15% and 20%. Šajn [10] suggests extending producer responsibility (EPR) and in-store collection by making producers and importers legally responsible for ensuring recycling or re-use of clothing. So far, the only EU Member State to enforce an EPR law for clothing is France (since 2006).

1.3 Regulations

E-waste is regulated in Europe through EU directives – the WEEE Directive 2012/19/EU [11] for collection, recycling and recovery targets for electrical goods and the RoHS (Restriction of Hazardous Substances) Directive 2011/65/EU2 [12] restricting six hazardous materials (e.g. lead, mercury, cadmium) in the manufacture of electronic and electrical equipment.

The textile sector has the OEKO-TEX® Standard 100 to remove harmful substances in the supply chain, including raw materials, intermediary, and finished products. The OEKO-TEX® certification system also introduces sustainable textile production (STeP) to benefit manufacturers of branded goods, retailers, and other organizations in the supply chain. There are also different ISO standards (e.g. ISO 14001, ISO 14020, ISO 14044) that companies can acquire to demonstrate environmental manufacturing or handling of products. [13]

Research on the topic and in-depth studies are lacking. This paper focuses on two e-textile projects developed collaboratively by designers, engineers, researchers and industry partners to provide new insight from different perspectives.

2 CASE STUDIES: CLOSED LOOP SMART ATHLEISURE FASHION AND BETALIGHT

There are attempts to create transparency in terms of environmental impact of smart textile products. E-textile development primarily happens in academic circles, material technology laboratories, and in maker communities, such as E-textile Summer Camp [14]. There is little overlap between academics, technologists and makers because they develop, communicate, and evaluate their work in different venues using different criteria in different languages. This paper aims to find common ground between academics, technologists and makers working in combined teams towards a common goal. We have observed two main approaches to tackling sustainability in e-textiles. First, product service systems that facilitate sustainable textile consumption [15]; and second, eco-design strategy principles that design products for repair, refurbishment and re-use [16]. Van der Velden et al. [17] demonstrate eco-design principles that facilitate eco-friendly material choices when developing e-textiles and propose reduced consumption.

The paper introduces two case studies from European Union Horizon 2020 funded WEAR Sustain program tackling the e-textile sustainability. The EU-wide network of textiles and technology professionals aim to create an ethical and sustainable wearable technology network [18]. During the first 18 months, the selected teams were supported by a larger network of expert stakeholders like IMEC, Digital Spaces Living Lab, University College for the Creative Arts, involving over 1,000 regional, national and international individuals and agencies. The programme provided 2.4 million euros across two open call competitions and involved over 125,000 individuals across Europe between March 2017 and January 2018 [19]. The projects presented in this paper (competition winners) complement each other in tackling sustainability in e-textiles. Closed Loop Smart Athleisure Fashion [20] proposes a lease-service-system for electronic athleisure wear to prolong product life and re-use of electronic and textile parts in a closed loop system. BETAlight [21] focuses on sustainable materials, design approaches and techniques. Both case studies represent development for the maker in relation to industrial adaptation. BETALight focuses on material qualities and allows in-depth discussion on combinations of materials regarding environmental sustainability. CLSAF exemplifies the service design approach believed to contribute to a more sustainable textile and fashion system. The projects are presented in more detail below.

BETAlight (Figure 1, Figure 2), developed by a group of experts from e-textile design, e-textile production, human computer interaction, electronics and programming, is a flexible light source worn on the body that allows the user to adjust its shape, orientation, brightness and light temperature. BETALight allows the wearer to create personal illuminated spaces nearby or on the body. The specially developed click-clack system switches the light ON/OFF, controls brightness and adjusts the light temperature. The fully textile circuit makes the light source flexible, thin and lightweight. The shell uses a mono material to facilitate recycling.

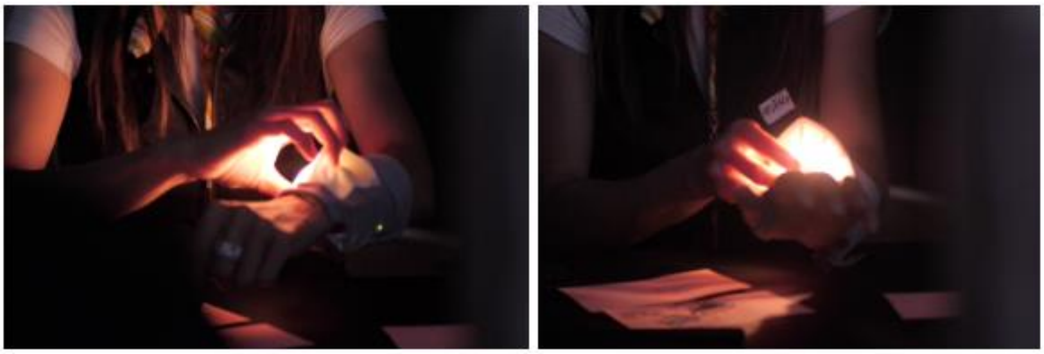

Figure 1. BETAlight personal light space click-clack system

Figure 2. BETAlight personal light space, developed by Tanja Döring, Barbro Scholz, Esther Stühmer and Axel Sylvester. Photograph: Tarvo Tammeoks. Concept video: *https://youtu.be/ilU9Yqpy-gE*

Figure 3. One example of the Closed Loop Smart Athleisure Fashion (CLSAF) collection developed by Marina Toeters, Margreet de Kok and Melissa Bonvie. Photograph: by-wire.net/clsaf. Concept video: https://youtu.be/6NHGZ1gooNM

The CLSAF collection (Figure 3) is a line of shirts that monitor the wearer's heartbeat and respiration. Based on the Holst Centre's advanced printed sensor technologies using flexible substrates [22], the laminated sensors are designed to produce casual clothing using traditional machinery. The lease and recycle system forms a closed loop for the user – in some parts using the recycled material Econyl®. De-laminating the electronics from the garments after use for recycling is also planned. The closed loop system is a sustainable way of producing, wearing and disposing of garments.

The two cases support [16] presented eco-design strategy for e-textiles, which stated that waste prevention was more important in the design stage than recycling, and designers should avoid obsolescence and endeavour to prolong the life of e-textiles. This could be achieved by designing products with repair, refurbishment and re-use in mind. Niinimäki and Hassi [8] explored the possibility of achieving more intensive recycling by making garments part of services systems, which requires a systems thinking approach from the start of a project where different stakeholders are concerned.

Next we will look at qualities of sustainability in the context of environmental, societal and economic sustainability, as developed by Kuusk et al. [23], to analyse the projects. Even though we focus on environmental sustainability we acknowledge the importance of the socio-cultural and economic contexts of both textiles and technology.

3 QUALITIES OF SUSTAINABILITY IN CLOSED LOOP SMART ATHLEISURE FASHION AND BETALIGHT

3.1 Methods

Kuusk et al. [23] described eight sustainability qualities (SQ) while framing smart textiles (including e-textiles) in the context of environmental, societal and economic sustainability. The work drew from a portfolio of interactive textile projects. Textiles and technology were integrated in various levels in the projects, and expert interviews identified the values related to sustainability. The eight identified sustainability qualities are: Minimizing Consumption, Controlling Energy and Chemical Use, Developing Constantly, Caring for Longevity, Supporting Meaning Creation, Updating the Product, Empowering Positive Emotions, and Building Relationships. Below we reflect on the two case studies in the context of the eight SQ-s.

3.2 SQ1 Minimizing Consumption

SQ1 Minimizing Consumption refers to slowing down the consumption of textile products by introducing properties offered by interactive textile services. Allowing textiles to have novel properties enabled by technology makes them relevant in diverse situations and users may keep the items longer. However, these properties should not make the original items less functional, promoting even more consumption.

The BETALight team worked hard at using materials with a minimal ecological footprint – recyclable, yet maintain quality. Therefore, material choices were made to minimise ecological footprints and maximise local availability. The majority of the product is made of Econyl® nylon. The material can be regenerated into the same quality as virgin nylon, making it easy to recycle and re-use and ensuring minimal material consumption [24]. Having electronic circuits produced in Europe facilitates keeping a close eye on production. Conductive textiles connecting sensors with the LEDs were set up as modular patches which can be disassembled. Econyl® made by Carvico and Aquafil SpA in Italy was the only mass-produced component used, since it met all the requirements for environmental sustainability and physical properties.
The CLSAF leasing system looks at minimizing consumption from a system perspective. With the agreement of the wearer, it enables producers to track garment use and performance. Based on tracked data the software is able to judge whether the garment should be replaced, recycled or can be reused (by another user). The leasing and tracking system contributes to its optimal use.

3.3 SQ2 Controlling Energy and Chemical Use

SQ2 Controlling Energy and Chemical Use is about reducing the resources and toxins used in producing and using the items through their lifetime. Cotton production depletes 2.6% of global water. It leads to reduced freshwater reserves causing drought in areas of cultivation and general damage to the water environment [25]. The use of fertilizers, pesticides and chemical dyes needs monitoring. The user must have sufficient information to care for the textile at home with minimal environmental impact.
BETAlight avoids over-production, unnecessary material and energy waste, and reduces emissions for transport and meetings through local production. Cutting maximises efficiency to avoid wasteage (Figure 4). Moreover, a waste sorting plan for the production company ensures that metal-based components, like electronic parts, are separated from the nylon waste during manufacturing stages.

Figure 4. BETALight sleeve pattern

Fabrics were selected from European manufacturers based on their sustainability statements. For example, Carvico produces infinitely recyclable regenerated nylon. For CLSAF, the sensor is printed using silkscreen printing of conductive ink on TPU. The conductive ink contains silver chloride. This should not end up as landfill, so a proper recycling process is necessary. During the project the team developed the de-lamination process to separate the sensor technology and garment in preparation for reassembly and reuse. A chemical process was found so the sensors can be reused at least 5 times. This is included in the project's business strategy.

3.4 SQ3 Developing Constantly

SQ3 Developing Constantly means adapting in time. How can smart textiles be used several ways for different purposes? New uses could emerge when the need arises.

In BETALight, rigid electronics, such as PCBs, and the power source are applied using snaps. This makes it possible to remove them for repairs or when a more efficient and sustainable option becomes available.
The CLSAF leasing model promotes continuous contact between the wearer and the producer or service provider. Therefore, software updates, training and the actual garment can be easily upgraded, changed or even exchanged with another wearer.

3.5 SQ4 Caring for Longevity

SQ4 Caring for Longevity is about durability and maintenance to ensure longevity. The user needs accurate and simple instructions on how to care for the textile.

Washability is something to consider when combining electronics and textiles. The former does not mix well with water, while the latter needs regular washing. BETALight has solved the problem by making the electronics and power source removable so the textile can be hand washed according to instructions on a care label attached to the product.

CLSAF targets busy, fashionable women. Their leasing model involves a cleaning service, as well as re-use/recycling processes to ensure the material is used to its full potential. And the wearer does not have to worry about the maintenance of the garments. Women take fresh garments on arrival at the gym and leave them for the care service as they leave. This concept is still in prototype phase and being discussed and tested with manufacturers and gyms.

3.6 Supporting Meaning Creation

Supporting Meaning Creation is about triggering user creativity. The textile is an open canvas to be modified as desired.

BETALight aims to provide information about the materials and production techniques used as well as an open source platform where customers and interested individuals can contribute to optimizing the product idea and production based on their experience and needs. It notifies users when more sustainable components become available and about changing one component for another.

CLSAF garments can measure the wearer's heartbeat and respiration rates. What the wearer does with this information – sharing, learning, interpreting, ignoring, adjusting training programs – is up to the person. Software to support the use of data is being developed in collaboration with potential marketing partners and service stakeholders.

3.7 SQ6 Updating the Product

SQ6 Updating the Product is about the item's ability to adapt to the changing needs of the user. Both the textile and electronics could potentially encourage the user to keep using the product without time limitations (newer compatibility requirements, broken seams etc.).

The electronic components in BETALight are attached using snap buttons. This allows the textile and electronics to be taken care of separately and if necessary to be exchanged independently. The user may adapt the product based on their needs and desires.

In the Closed Loop project, there is continuous contact between user and service provider. Therefore, there is a stable stream of feedback allowing the service to be upgraded as needed.

3.8 SQ7 Empowering Positive Emotions

SQ7 Empowering Positive Emotions is about pleasant and intuitive use of e-textile products. The textile component creates a comfortable and familiar feeling for the user, while technology, bringing functionality to the item, is integrated to thoughtfully support intuitive use.

As a wearable light space BETALight can be worn on the wrist and it lights up through natural body movement when the user opens an origami inspired mechanism on the device. In the prototype the technology is operated by touching the textile, thus reinforcing soft, human qualities.

CLSAF (Figure 5) uses technology as visual inspiration. It creates a new form of semiotics in the fashion industry and connects to the materiality of the sensory technology rather than its functionality. The purely functional sensory forms are seen as inspirational and attractive.

Figure 5. Visual communication from the Closed Loop Smart Athleisure Fashion (CLSAF) collection developed by Marina Toeters, Margreet de Kok, and Melissa Bonvie. Photograph: by-wire.net/clsaf.

3.9 SQ8 Building Relationships

SQ8 Building Relationships is about creating connections between the user and their environment. The e-textile solutions need to take care of the social needs of the wearer.

BETALight creates a personal light space allowing a non-physical space definition which is adaptable. The use of light as a space-defining material is far more subtle than a physically closed space. The added value is the privacy created by an adaptable light source that is physically connected and spatially related to the body.

The CLSAF project in its current phase is more about creating relationships between all the production, business and service stakeholders than between the users. CLSAF project can be considered a Product Service System (PPS). It requires "a whole suite of technically advanced elements and systems that function through a connecting infrastructure. The service aspect is often also not one but several services, each consisting of many elements, relationships, and interdependencies" [26]. A complex web of 44 stakeholders has been created to develop and implement the Closed Loop.

For this system to be successful, enhancing relationships between stakeholders is needed to gain loyalty and therefore should be an aim [27]. Trust cannot be built overnight. A large number of relationships is challenging to maintain and to understand the organisational complexity, a successful business model should aim to limit the amount of stakeholders. However, this does not mean that stakeholders should be left out, as this would mean a loss of valuable input to develop and implement such interactive fashion.

We have presented the two case studies through the lens of Qualities of Sustainability to highlight the insights they offer (mainly) environmental sustainability. Since these cases focus on material choices and service systems – major drivers of wastefulness in fashion and textiles – we present the synthesised learning outcomes in the following discussion.

4 RESULTS AND DISCUSSION

The e-textile field requires more extensive research on sustainability. As makers and material-based practitioners we tackle mainly the environmental aspects of sustainability. Currently, there is a lack of standardization and waste streams for smart or electronic textiles. It is essential to start taking the first steps and establish guidelines for industry, customers and developers. Collaboration between experts from different fields sharing a common goal supports the creation of environmentally sustainable products. The designers of these cases focused on sustainability in developing their products. The Sustainability Qualities [23] helped us to organise and articulate that tacit knowledge embedded in the product, maker and materials. The different aspects of the developing products were put in focus, thus emphasising their weaknesses and strengths.

Both of the case studies aim to **minimize material consumption.** The developers took the ecological footprint of the materials into consideration when creating the prototypes and specifications. They chose to use infinitely recyclable, regenerated nylon material; they made electronic components removeable for easy replacement; they kept track of the clothing by applying a lease system for care, recycling and re-use. The project teams **controlled the product's energy and chemical use** by using recyclable materials, local production, and avoiding over-production.

The projects **continue to develop or update** while in use as they have been designed with an afterlife of disassembly, repair and software updates. The e-textile solutions we viewed **considered longevity** through maintenance processes. CLSAF does that by building up a leasing service that keeps the items maintained and carefully used and BETALight by providing care instructions.

The makers of the two projects have thought about **creating valuable experiences and empowering positive emotions** by creating a personal light space for a temporary retreat and by allowing the customers to actively contribute to the final product and its development (BETALight); and by seamlessly maintaining the product and facilitating a stakeholder network (CLSAF).

Mauser et al. [28] show how World War II already highlighted the necessity for integrating research from different disciplines. Politics and military needs demanded cross-disciplinary research. Today, industry and end-user needs must also be considered from the beginning of the e-textile product development process. Therefore, it is crucial to consider multidisciplinary cooperation between different stakeholders.

E-waste and textile waste management should be prevented now, rather than repaired later, and raising awareness about the waste of smart textiles is essential. Bruggeman [29] draws attention to the increasing awareness in

Western culture and society of the lost connection between fashion and materiality – the knowledge of how and where textiles are made. Nevertheless, it is necessary to create clear guidelines for what the user should do when their smart textiles near the end of their life-cycle. By returning the item to the producer the CLSAF example makes dealing with waste remarkably easy. Another option is to establish numerous collection points – large store chains, electronic shops, etc. It is fundamental that an easily understandable system is created for the end-users.

Although, there are only a few e-textile products on the mass-market, interest in production is growing [2]. Manufacturers are interested in cheap and fast solutions, which may however be harmful to the environment. Niinimäki and Hassi's [8] paper includes manufacturing strategies for reducing the environmental impact of textile and clothing productions. However, companies are unprepared for radical change, and so it is critical to provide the industry with tested and clear systems that could be integrated into existing models. The BETALight product design allows for production within current manufacturing models by putting more emphasis on material usage and eco-design elements, while CLSAF promotes a more environmentally friendly, closed-loop manufacturing method and focuses on the relationships between stakeholders in the loop.

Lack of standardisation of smart textiles and their waste management seems to be a significant barrier for industry entering the mass-market. Creating clear systems where there is no standardisation of the product's life-cycle is highly complicated. The Sustainability Qualities used in this work could assist in giving an overview for environmental (but also, societal and economic) sustainability while developing e-textile solutions.

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