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Life cycle assessment and eco-design of smart textiles: The importance of material selection demonstrated through e-textile product redesign

Natascha M. van der Velden [a,*], Kristi Kuusk [b], Andreas R. Köhler [c]

[a] Faculty of Industrial Design Engineering, Department Design for Sustainability, Delft University of Technology, Landbergstraat 15, 2628 CE Delft, The Netherlands
[b] Department of Industrial Design, University of Technology Eindhoven, Den Dolech 2, 5612 AZ Eindhoven, The Netherlands
[c] Oeko-Institut e.V. Institute for Applied Ecology, P.O. Box 17 71, 79017 Freiburg, Germany

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ABSTRACT

Smart textiles have progressed well beyond the laboratory stage. A growing community of smart textile designers utilises engineered materials and advanced manufacturing technologies to create marketable products. To implement an environmentally conscious way of product innovation, the environmental impact of such products needs to be taken into account already at the early design-stages. A life-cycle perspective on the consequences of design choices can guide the implementation of eco-design measures. However, not much literature is available thus far to empower designers in making sustainable design decisions.

To meet this need, this article presents a life cycle assessment (LCA) of a wearable smart textile device for ambulant medical therapy. The case study focuses on material selection, since this aspect is one of the most relevant choices at the prototyping stage. The eco-cost approach was used to compare the LCA-results of the original prototype design against various eco-redesign options.

The results suggest several priority areas for environmental improvement. One possibility is the replacement of silver based conductive yarns by copper based alternatives. Another finding suggests the use of acryl instead of wool. The case study results are the starting point for further discussion on the role of designers with respect to responsible eco-design.

1. Introduction

1.1. Background and hypothesis

Technological advancement of smart textile materials and manufacturing processes is developing rapidly. New types of materials, technologies and knowledge allow designers to integrate smart solutions on smaller and less visible scales and to obtain results faster than ever before. This offers a lot of opportunities, but raises new questions and concerns as well.

The above developments have led to an enormous variety of smart textile prototypes that have been presented at fairs and exhibitions. The textile sector embraces these innovative ideas as they offer plenty of possibilities for novel products and open up new business opportunities for the textiles and fashion industry [43,50]. Innovations in smart textiles technology promise to add value to the consumer's life and satisfy the textile industry's demand for new market opportunities. Previous innovation cycles, and this concerns the high-tech sector in particular, showed how novel technologies unexpectedly proliferated the daily life of average consumers within a relatively short time. Examples of break-through applications encompass digital watches, mp3-players, smart phones, and tablet PCs. Smart textiles have a potential to become the next item in that row and observers of the smart textile innovation process forecast the technology to proliferate at the consumer market within a decade and become an integral part of future life styles in future.

Rich, unique, personalized material experiences [20,23] facilitated through smart textiles can result in an uptake of applications, such that smart textiles will gradually become more recognized and mainstream in daily used products [48]. However, these innovations and the high development speed involved have a counterpart as well: it raises concerns about environmental issues related to these trends.

A general observation is that smart textile designers, at least those working in small and medium sized enterprises (SMEs), are not well-educated and/or informed about issues related to design for sustainability [31]. There is a knowledge gap to bridge, not only to support the decisions and to fill up the lack of environmental knowledge of these designers, but of their managers and clients as well. Since textile designers make numerous product development choices and influence the architecture of products based on market and user insights [51], this study is specifically aimed at this audience group.

The contemporary innovation process of smart textile holds the opportunity to implement environmentally conscious design right

* Corresponding author.
E-mail addresses: n.m.vandervelden@tudelft.nl (N.M. van der Velden), k.kuusk@tue.nl (K. Kuusk), a.koehler@oeko.de (A.R. Köhler).

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from the beginning. This may help preventing adverse environmental side effects of tomorrow's products [26]. Our assumption is that textile designers can significantly reduce the environmental impact of their smart textile based products. This, we further assume, will require a design decision making process in which they are well-informed from an environmental impact and eco-design point of view — e.g. make the right material choices [22,34] — and on relevant user scenarios, at early design stages. In close connection, it is assumed that designers could communicate these well-considered choices successfully to their management, their colleagues at marketing and eventually to the consumer.

This paper provides a case study of a smart textile garment for health applications. It is introduced here to serve as an example on the potential of eco-design of smart textiles and to illustrate that these relatively complex products can benefit from life cycle thinking. The first part includes a LCA to determine the hot-spots of environmental impact associated with the product's life-cycle. The second part of the case study shows eco-redesigns, using the results of the LCA and the implementation of eco-design strategies. The authors aim for this first e-textile eco-design case to be a powerful example and illustration for smart textile designers, from which they can learn what aspects are important to take into account (and conversely, which can be safely ignored) when they want to put eco-design into practice in their fast emerging sector.

To test the eco-design approach we present in this article, we introduce the following hypothesis: The implementation of eco-design can improve the environmental impact of a smart textile product — expressed in eco-costs — with at least 25%.

The next sub-section (1.2) outlines the main environmental problems related to smart textile design while sub-section 1.3 reviews the status quo of LCA of e-textiles in literature. Section 2 explains the method of the study presented in this paper. Section 3 describes the case study of a specific smart textile product for the health application, called 'Vibe-ing'. Sub-sections 3.1 and 3.2 introduce the case-study and describe the prototype, while in 3.3 the LCA of Vibe-ing is being discussed. 3.4 then describes the application of several eco-design strategies on Vibe-ing based on analysis of redesign solutions. The paper ends with a discussion and conclusions in Section 4, including a discussion on the limitations of the research, the results pertaining to our hypothesis and recommendations for further research.

1.2. E-textiles and the environment

E-textiles are regarded as a subset of smart textiles, also referred to as 'wearable electronics'. These products differ from traditional fabrics in that analogue and digital electronic components — for example, small computers — are (more or less) seamlessly integrated into the knit, weave or other soft crafts technique [8,46]. The purpose of this integration is to obtain new functions of textile materials or, from the perspective of the electronic sector, to enable novel user experiences with electronic products that have not been soft and flexible thus far [25].

As the innovation system is yet at its pre-mature stage [7], a lot of functionalities are achieved by attaching or integrating the electronic components in- or onto the surface or to the textile product [29]. One step farther ahead in innovation and electronic functions is integrated right into fibres or yarns directly [32]. In essence, the fast-developing electronic sector bands together the change-minded fashion industry in an endeavour to create a new category of smart wearable products [44]. From an environmental impact point of view this reveals a lot of challenges [25] and hot spots comprise energy — and battery consumption; use of toxic materials and — of scarce resources and recycling difficulties. The same source highlights as well the attitude and expectations of smart-textile designers and — SMEs towards sustainability and LCA (*ibid.*). It indicates that the majority of SMEs do not see the environmental performance of products as a driver for innovations and environmental aspects are presently regarded to have inferior importance as compared to product functionality.

In terms of environmental concerns, it seems that there is still room for a prevention oriented approach: so far, smart textile technology has not produced a 'killer application', despite this already was discussed during the 7th edition of the Smart Fabrics conference in 2011 [42]. The 'kick-start of the smart clothing business' that has been announced with such conviction did not take place yet [6]. Not many smart textile products can be seen in the streets today and they are not yet integrated in the ready to wear clothing segment. While it is true that the integration of electronics in sports activities and sportswear is a growing trend, the consumer's need to self-monitor can also be addressed by means of separate accessories, e.g. a breast — and wrist device [37]. Likewise, smart textiles are indeed penetrating the healthcare — and the protective clothing markets [33,41], but again these are considered niche applications when compared to the worldwide apparel sector.

A possible explanation for the delayed market appearance of smart textiles might be due to technological limitations: E-textiles are yet not washable and the reliability is often poor. Then again, integrated electronics in textile cuddly toys (such as the once-ubiquitous 'Furby') and e.g. children's shoes (with flickering lights like 'Skechers') already are more and more present and this could indicate that the moment e-textile clothing products really break through might not be too far away.

From this observation it can be concluded that it is timely and opportune for the environmental problems surrounding e-textiles to be explored in depth so as to positively influence smart textiles innovation and development.

1.3. LCA and eco-design of e-textiles

LCA is a quantitative method to environmental assessment according to the international standards [16,17]. It is widely used to study the potential environmental impacts of processes, products and services through the whole life cycle from cradle to grave [14,39]. This encompasses the raw-material acquisition, the production processes leading to products, transport processes, the product's use phase and its end-of-life (EoL) stage. By means of the LCA-methodology, the environmental impact of a product can be assessed and compared with other products or alternative design solutions.

Eco-design comprises the integration of environmental aspects into technology development and product design. The overarching aim is reducing adverse environmental impacts throughout a product's lifecycle [10]. According to the EU Eco-design directive [12] a greater focus in eco-design is cast on the product's energy use and other environmental aspects during its complete life cycle. The Eco-design Directive emphasises the important role of the conception and design phases, before a product is manufactured and brought to market.

Both LCA and eco-design are extensively described in scientific literature, for example by Ehrenfeld already in the late 90s [11]; by Klöpffer [24] and Niinimäki and Hassi [36]; and recently by Mirabella et al. [35]. These and many other articles highlight the value of the implementation of LCA and eco-design for environmentally conscious product development.

The bibliographic database Scopus reports almost 500 articles with 'eco-design' in the title, abstract or keywords over the last five years (2010–2014), and almost 6400 with the term 'LCA'. Although a growing trend is visible, both subjects together in one article are less common (118 articles found). If the emerging technology 'smart textiles' or 'e-textiles' are concerned, only a few studies have been conducted thus far [25,27]. Schischke et al. [40] refer to the LCA-to-go project (see Section 1.1), which presents a simplified LCA approach for smart textiles. Similar results (0 papers found) came up when searching for combinations with the term 'wearable electronics'. The literature research highlights the fact that not many scientists work on eco-design of smart textile products and LCA-base knowledge is fairly scarce among technology developers and design practitioners.