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The cross-section of a multi-disciplinary project in view of textile design

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Abstract: We describe the development path of a smart textile-design method, stemming from a collaborative multi-disciplinary project, with three university departments: chemistry, design and electrical engineering. While the project focus was not originally on textiles, the needs for flexible semiconducting materials led to experiments with a zinc oxide(ZnO) semiconductor deposited over cotton substrate, thus shifting the focus towards textiles. A series of exchanges and actions between the three disciplines, raised the awareness of the need for textile-design methods regarding electric materials. Taking this as a starting point for generating new knowledge, drawing from the strengths of both textile design and engineering, an approach to develop smart textiles was developed. In this paper, we discuss the overall project, and identify the key stages in the interdisciplinary collaboration, in terms of textile design practice, while reflecting on the outcomes, which enabled paving the way for interwoven design and scientific knowledge embedded into smart textile design practice.

Keywords: smart textile; process; interdisciplinary research; ZnO yarn

Introduction

Smart textiles and -clothing have advanced to the point, where smart material development suitable for textile design is focusing on the fibre level, however, there is a distinct gap between the technologists and the designers (Cherenak & van Pieterson 2012; Stoppa & Chiolerio 2014; Castano & Flatau 2014). There are examples where textile design is indicated as central, but the designer's role is not always indicated in the process (Quirk, Martin & Jones 2009; Martin et al. 2009; Karrer et al. 2011), let alone noticed as relevant (Chan et al. 2012), even though the research would otherwise be highly relevant in the field of smart textiles and -clothing. There are several examples aiming towards smart clothing and textile development, where the technology is intended for textile use, but there is no input from the textile designers (Lee et al. 2015; Chen et al 2014; Löher et al. 2008), or they are only briefly mentioned in the acknowledgements (van Pieterson et al. 2011; Zysset et al. 2012; Mattana et al. 2013). Furthermore, there are already several examples, which have successfully utilised an interdisciplinary approach (Jost, Dion & Gogotsi 2014), however they are often textile-led (Berzowska & Skorobogatiy 2010; Seager et al. 2013; Kuusk, Kooroshnia & Mikkonen 2015) or they have considerable commercial interest (Zhou et al. 2016; Devendorf et al. 2016).

Despite this gap, there is an interest to understand both the development and the usage of materials suitable for smart textiles, specifically suited for textile design methods. With the textile design at the centre, the designer interacts with different scientific stakeholders, such as chemists and electrical engineers. This brings forth the need to be able to communicate, and to understand each other with issues, e.g. time scales of process (the time needed for conducting different processes), or keypoints in time (the moments that are important or relevant to knowledge generation that provide distinct impact to the process), which vary between the disciplines.

Textile design and its teachings are rooted from disciplines of art, craft, design, and technology (Igoe 2010), providing different professional roles that range between creative, social, industrial, commercial and associated practices (Gale & Kaur 2002). In an early defining paper, Moxey (1999) has touched upon the multi-disciplinary nature of a textile designer's role: a hybrid artist-technologist-social scientist, providing innovation, variety, and consumer satisfaction within the fragmented textile industry. Similarly, Wiberg (1996) draws attention to the 'intertwining of the scientific-technological, the conceptual-transcendental and the artistic-intuitive' presence in the every-day practical work of a textile designer exemplified by the colouring of fabrics. In order to utilise these multi-faceted skills, in all stages of the design, development and production process, the textile designer collaborates and communicates with other professionals, i.e. engineers, technicians, logistics staff, marketing staff, salesmen and management (Bang 2010). However, as the use of textiles is furthermore expanding parallel to the development of textile material diversifying, academic research points to textile design encompassing an even broader range of practices and different forms of collaboration.

The Heat Harvest project discussed in this paper is a multidisciplinary collaboration between three Aalto University schools: Chemical Engineering (CHEM), Electrical Engineering (ELEC), Arts and Design (ARTS). This project is part of the Aalto Energy Efficiency Research Programme, and the three schools approach the topic of energy harvesting from their respective perspectives, to develop materials and methods for extracting energy from ubiquitous waste heat, while looking for innovative concepts for new applications. Although the project is multidisciplinary, the science-led project revolves around atomic layer deposition (ALD), an advanced thin film coating method that fabricates ultrathin, highly uniform material layers by exposing the surface of material to alternate gaseous species. An important benefit of this method is the possibility of deposition on a variety of substrate shapes and sizes (Jur et al. 2011). Zinc oxide based thin films were exploited in the project as a model thermoelectric material system (Tynell 2013). The deposition of n-type ZnO thin films and coatings using ALD is a familiar process at Aalto University (Tynell 2013) and worldwide (Tynell & Karppinen 2014). For a full thermoelectric module, p-type thin film materials would be required; search for such materials was another goal in this project for the chemistry partners.

Drawing from the definitions laid out by Aboelela et al. (2007), this project started as a multidisciplinary project, i.e. parallel research sharing similar research questions. However, it has gained interdisciplinary characteristics, where we utilise data from different sources across disciplines, and use methods from different fields to examine the same core issues. Ideally, the aim is towards a transdisciplinary process, where the different fields can utilise the methodology and eventually merge into one discipline. Therefore, to help understand the divergent role of a textile designer in today's textile practice and the reciprocal knowledge transfer from and to textile design within a multi- and interdisciplinary material and product development setting, starting from the early workshops (Townsend & Ylirisku 2015), we present the work done towards the development of semiconducting ZnO-cotton material (Sarnes 2015; Karttunen et al. 2017), and the subsequent development of a methodology (Townsend & Mikkonen 2017) suited for the development of electronic smart materials. We emphasise, that the perspective in this paper is that of a textile designer, even though the collaboration has been with both electrical engineers and chemists.

In this paper, we discuss the project and identify the key stages, in terms of textile design practice and in the interdisciplinary collaboration, while reflecting on the sensory aspects of material, methods and human interactions. While the overall project has consisted of other parts, such as a development of a solar collector, we focus only on the aspects related to the textile-design-based measurement methodology.

Related Work

Academic research in textile design has been governed by technical studies positioned within science and engineering knowledge frameworks (Kane et al. 2015). Increasingly, however textile designers are undertaking research into technical areas with creative intentions, utilizing artistic modes of inquiry. As our project focuses on the multidisciplinary material development, a look at the creativity on textile (material) design process, as well as the process itself, is needed.

Textile practice to creativity

In general, textile design can be considered as referring to the 'process of creating designs for knitted, woven, printed and mixed-media' (Steed & Steveson 2012), lace-making and knotted fabrics, as well as including more recently developed sub-fields of textiles, i.e. smart- and 3D printed textiles. However, the design process, or its combination of phases, and stakeholders can differ according to the context a textile is created and used within, e.g. art, craft, industry, the type of textile techniques and technologies employed, in addition to the relation of textiles to products, e.g. as 'a raw material' for different products and end uses, or, a specific designed material that is either de-attached or formed as an integrated part of a product (Nilsson 2015). In fact, Nilsson suggests that 'there is no right way to design with textiles', however the respective influence of process, interaction of the material and the character of the textile design needs to be acknowledged and taken into consideration.

The diversity within the textile and clothing field entails the need for different types of designers (Wilson 2001). However, while textile design has a long tradition in creative practice, textile design has had less presence in the general discourse on design, or design research compared to many other sub-fields of design (Bye 2010). The different practice of a textile designer within the textile industry was highlighted in Wilson (2001) and further summarized into a generic five-phase textile design process framework by Studd (2002). Bang (2010) proposed changes to the design process by exploring the emotional value of applied textiles through implementing user- and stakeholder-centred approaches. Another approach taking the identification of the end-user needs as a starting point, by McCann, Hurford & Martin (2005), guides the designers towards identifying and addressing both technical and creative aspects. The authors propose a 'critical path' tool to address the gap of 'common language' between a creative and systematic design process in the development of smart clothing.

Despite the approach or process, a common factor in all design activities is creativity in its different form: whether a less evident 'form of a creative event', or 'solution possessing some degree of creativity' (Dorst & Cross 2001). As an example, creativity has been discussed in regards to the textile and/or garment process within a framework for a system view of creative success within fashion textiles (Moxey & Studd 2000). Furthermore, Strickfaden, Stafiniak & Terzin (2015) have provided insight into understanding creativity in the design process through influence and inspiration, and how these aspects of creativity are transformed into projects. Within the domain of design and material, creativity has surfaced as 'creative material development' (Thompson & Ng Yan Ling 2014:207). This approach combines technical and emotional aspects of material development to allow creating products that offer new material experiences to the user, thus placing the designer into a more leading position in developing new material. This is also echoed by Karana, Pedgley & Rognoli (2014), quoting: 'Thus, when a decision is to be made on the materials to be used in a new design, competence is needed in predicting and defining both the experiential qualities and the performance qualities of materials'.

Textile designers in multi- and interdisciplinary projects

Three early examples of interdisciplinary research topics, interactive olfactory textile surfaces (Tillotsen 1997), digital 3D textiles (Harris 2000), and spray-on fabric (Torres 2001), cut across the fields of textiles, fashion and science (Sams & Black 2013). In a research project involving the development of linseed fibre material (Härkäsalmi & Koskinen 2010), the textile designer exploited knowledge from fields, e.g. microbiology and agrotechnology. They (ibid.) underscored the importance of multidisciplinary research, and how a designer-researcher can take the leading role in a material development process after obtaining the relevant fundamental scientific knowledge, and when having knowledge of all stages of the production chain in the development of novel raw materials. This has been further exemplified in the DWOC-project (Aalto University et al. 2015), which has origins in multidisciplinary material development (Michud et al. 2015), suggesting contexts and uses to guide the development, and producing exemplars and providing methods to utilise new material (Itälä 2015); an approach further explored in CHEMARTS (Kääriäinen, Niinimäki & Lindberg 2017).

In a collaboration between a textile design, optical engineering, dyeing chemistry, and colour analysis, Akiwowo et al. (2014) have developed a method utilising a laser to "engineer dye onto the fabric with high-resolution graphics". During the development, they configured the colour data through both visual and numerical means, "demonstrating the relationship between a specific vector grid, tonal density, and energy density" (Akiwowo et al. 2014:144). Notably, the "energy density provided a common language", to achieve controlled and repeatable colours. A successive project focusing on laser modification of textiles describes a research methodology, attempting to illustrate the synthesis of scientific and creative approaches (Morgan et al. 2014). Partly implemented with the same team, the work falls within textile design, textile chemistry and textile engineering. The methodology describes four phases, with iterative data creation at the early phases, followed by quantitative testing and design development in the latter phases. They emphasise the importance of tacit knowledge during the knowledge generation, and describe how it combines together with scientific knowledge, drawing a clear picture on the research collaboration. They specifically mention that the reciprocal relationship between the exploration and experimentation was "foundational to the momentum and 'success' of both projects, further stating the importance of work being "pulled back" to exploration phase, to maintain the design direction. Both projects demonstrate an approach in which knowledge was generated as the design practice advanced (Kane et al. 2015).

As an example of technology-influenced design process development, Parsons & Campbell (2004) present and analyse five digital printing projects. The paper demonstrated, how the experience and knowledge of the technical constraints and possibilities influenced the design process. As the solutions to sub-problems were found, the shift in focus addressing design features gave more space over solving technical issues, thus changing the design process into a linear phase-oriented procedure.

Mapping the development path of the project

To illustrate each stage and detail of the work done between 2013-2017, the project was drawn as a map, shown in Figure 1. While the map is not an exhaustive representation of all activities of the entire project, it depicts activities that either directly involved the design school, or had an impact to their work.

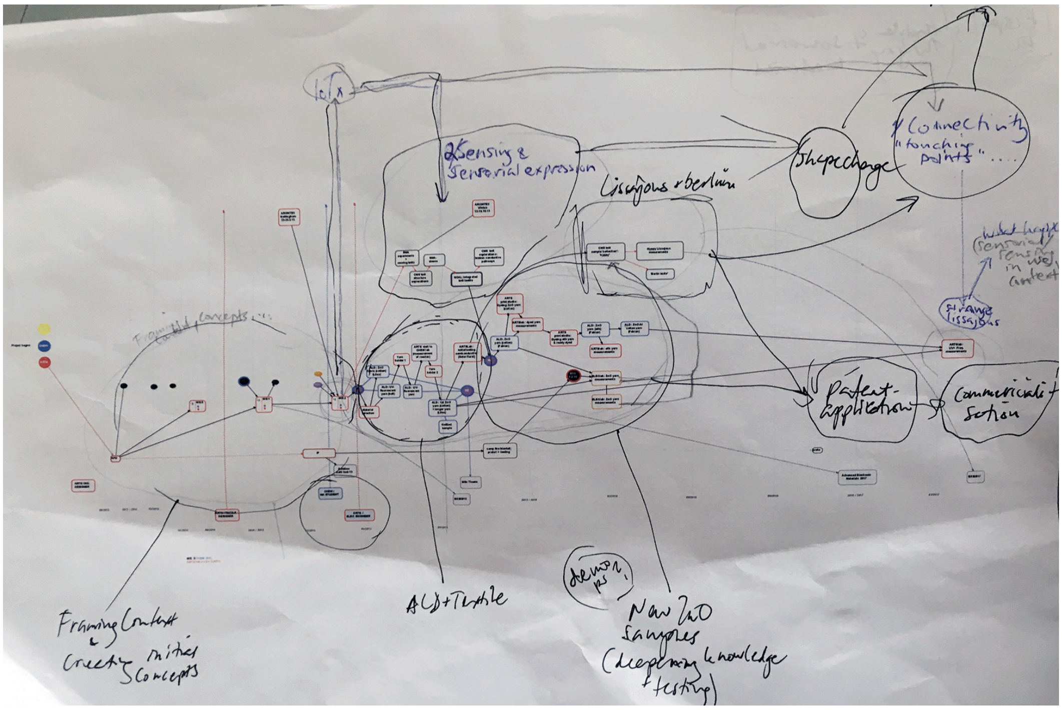


Figure 1. Project map with comments

The map was done to get an understanding of the interconnectedness, and to be able to analyse which steps were significant. In the map, each activity or moment of importance was visualised as a node: meetings, laboratory visits, measurement days, significant development activities (e.g. dyeing) and workshops, totalling over 50 separate points (excluding dissemination), some of which may span days or even weeks. They indicate when a key finding or an experimental outcome was gained. From each step, the most significant directions were laid out, e.g. when a meeting resulted in an access to a laboratory of a different School.

The mapping was analysed, and simplified to a set of clusters, shown in Figure 2. Each cluster contains activities that have a common theme and textile-specific actions, discussed in the following text. Notably, the textile designer has been involved in all of these parts, apart from the very first workshop.

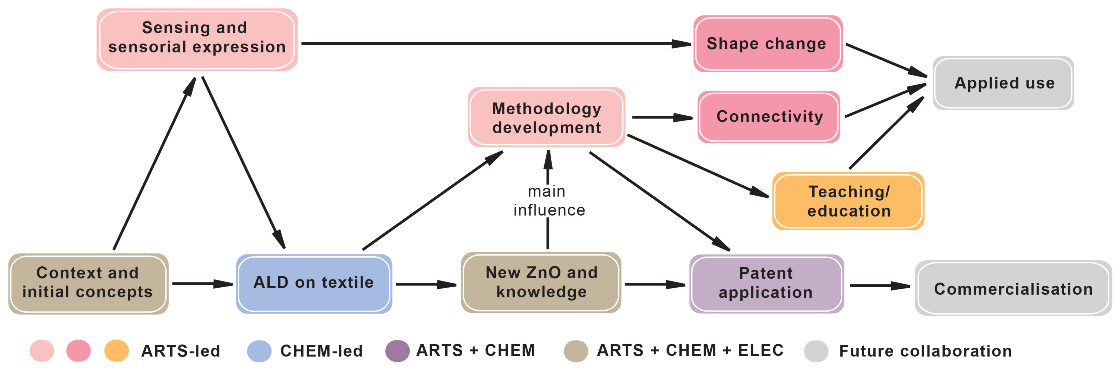


Figure 2. The simplified path of the project

Context and initial concepts

Overall: Context and initial concepts

The initial role of design was to develop novel product concepts that utilise thermoelectric components that are based on identifying different locations where energy is being wasted. This resulted in two MA-level courses, Advanced Product Design in 2013 and Interactive Prototyping in 2015, having themes with energy harvesting from heat. The results of these courses have been included to the project with consideration towards implementation. In addition to the first workshop with participants from Aalto-university and Tokyo University of Agriculture and Technology/ Japan, two design-led workshops for design and science researchers of the project were conducted. The aim was to explore a way to engage technically oriented researchers into the consideration of material sensing and engagement, as means for creating 'an experiential context' for the subsequent development in the project. A paper was written, describing and reflecting on the procedure for facilitating materials-based ideation with multidisciplinary participation (Townsend & Ylirisku 2015). After these, the direction of design within the project changed towards hands-on textile material development.

Textile-specific actions: Context and initial concepts

Paragraph The textile designer's role was to create exemplars, and introduce textiles and textile-materials in a broader sense to the overall research teams, i.e. to open up the possibilities of textiles, to explore how textiles could be combined with thermal energy harvesting; in essence, to open up potential areas of innovation. Two major outcomes of this step were the selection of textile as a substrate for the ALD, and the inclusion of chemistry MSc thesis worker focusing specifically on cotton substrate. After this, the textile designers research partner in ARTS changed from a software scientist to an electronics engineer.

Sensing and sensorial expression

Overall: Sensing and sensorial expression

This cluster focused on the effects of heat, and how a person would perceive the aspects of heat and tactile stimuli in on-skin applications. The work consisted of a preliminary study of a wearable SMA-actuated sleeve, originated from the workshop ideation. Two sleeves were created with surface shape change properties, and were compared to a third sleeve without any integration. Laying groundwork for the future shape change-work, it was conducted in parallel with the ALD on textile step.

Textile-specific actions: Sensing and sensorial expression
The work in this step was textile-design led, although it was carried out with the electrical engineer. The process started with 'crochet sketching' and table-machine knitting, and final samples were developed using a Stoll CMS industrial knitting machine, shown in Figure 3. The experiments suggest that the application context, method of textile integration and the active and static properties of the textile are all relevant for experiential smart textile design.

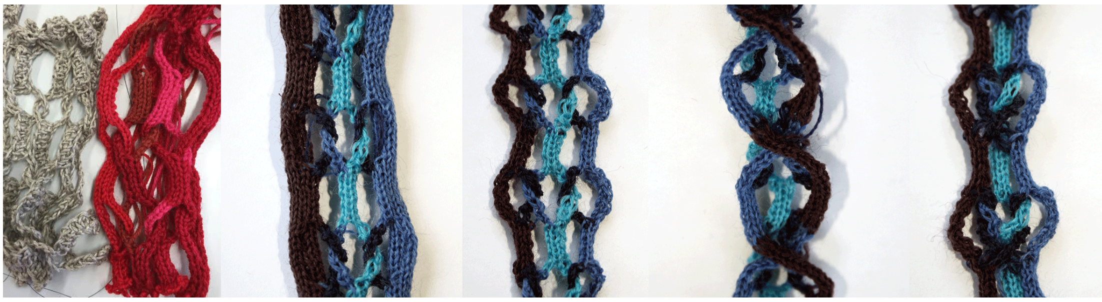
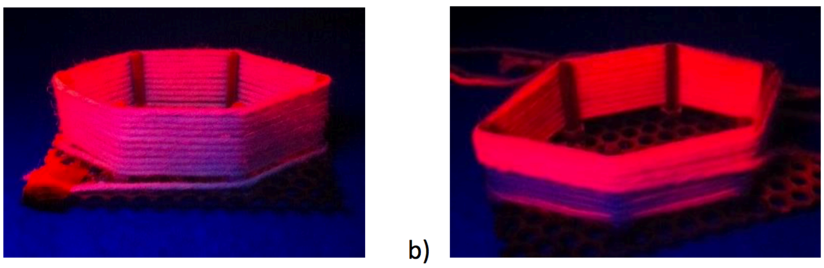


Figure 3. An example of the development work towards machine-knit samples

ALD on textile

Overall: ALD on textile
The work revolved around the MSc-thesis (Sarnes 2015), focusing on the atomic layer deposition of zinc oxide (ZnO) on cotton, in order to create an n-type semiconductor on a flexible substrate, suitable for energy harvesting using temperature differences. The thesis resulted in sets of ZnO-deposited yarns and textiles, which were evaluated for resistivity, as well as degradation due to e.g. moisture. As the cotton substrates differ from the standard glass- and silicon-substrates, this has led to considerable changes in the ALD parameters, due to fibres of the cotton forming a porous-type and fine-structure with ~10um size features. This work has been published in a scientific journal (Karttunen et al. 2017). Additionally, the chemists created an UV-fluorescent coating (Giedraityte, Sundberg & Karppinen 2015) for a cotton yarn to evaluate the suitability for ALD, shown in Figure 4., after which the first ZnO-samples were created.

a)



b)

Figure 4. UV-fluorescent yarns in the earlier sample holder
Source: Sarnes 2015

Textile-specific actions: ALD on textile
While the focus of this step was on the first atomic layer depositions on the cotton substrate, the textile designer contributed in two main ways. Firstly, by selecting and supplying sets of cotton yarns and fabric for the chemists, suitable for the temperatures of the ALD-reactor. Cotton was preferred due to, e.g. being easy to dye, enabling the use of textile-design methods later in the project. Secondly, to augment the ALD-reactor, the design school created a sample-holder, suitable for depositing to greater amounts of yarn, shown in Figure 5.

Figure 5. Yarn-holder with thick cotton substrate
Source: Sarnes 2015

Figure 6. Exhaust dyeing ZnO samples

From the textile-perspective, the yarn offers several benefits to other conductive yarns, being very similar to non-deposited cotton in both feel and visual outlook. Thus, the cotton-based yarns were explored in a variety of ways in the Design School. The project utilised standard resistivity-measurements for the yarns, which is a standard for the chemists to verify the yarn functionality. These measurements were followed by the design team. However, there were problems with the communication of the electronic properties, and their implications. The textile designer faced frustration, as the typical time-based measurements did not provide meaningful information in terms of textile design aspects. The results were seen electrically interesting, but when presented solely with numbers and overlaid sine waves, these were not expressive enough to see the connection between the electrical and the ZnO-yarn qualities. There were hints that the behaviour of the yarn changed with the frequency; along with something else we did not yet comprehend. Thus, to utilise the yarns in a smart textile development, the understanding of the signals needed to be developed. Furthermore, the textile designer indicated a need for yarns suitable for lighter garments.

New ZnO and knowledge

Overall: New ZnO and knowledge
Having the textile-design needs and suggestions as a starting point, this cluster steered the ALD on textiles; the request was initially for additional ZnO-yarns. These were to be thinner, for easier knitting, as well as for further experiments with dyeing. Furthermore, aluminium-doped deposited (ZnO:Al) yarns were provided as a comparison and reference to the other ZnO-yarns (Al-doping should increase the conductivity of the ZnO layer).

The cluster contained several testing days. Initially the electrical tests were conducted at the designers' laboratory to verify that the findings in the 'ALD on textile' were correct. Other tests were used to evaluate the frequency-related properties, as well as the DC-properties. To verify that those results were reliable and repeatable, they were re-done at the School of Electrical Engineering, in an electrically isolated room.

For the duration of the measurements, a lecturer and a laboratory engineer joined the team from ELEC, as well as an intern from design. These tests confirmed the findings; the test equipment gave matching results, thus allowing designer independence. There were also unexpected results, which prompted the ELEC staff to christen the samples as "magic yarn". However, during these measurements, the textile designer felt like just “sitting in and hanging around”, without getting anything out of the measurements. Thus, this frustration had to be addressed. To defuse it, a suggestion for visual measurements and a reference base emerged, being a major contribution to the work done in 'Methodology development'.

Textile-specific actions: New ZnO and knowledge

Paragraph Parallel to the testing, the textile designer selected new yarns for the ALD. Initially, the same cotton as before was selected to be deposited. After the deposition, some of the deposited yarns were dyed with reactive dye by the exhaust method, shown in Figure 6, as well as by pad-patch dyeing. All samples were measured before and after at the design school. This was continued with a selection of thin silk yarns; using the same dyeing methods as before, but also including commercially dyed yarn. These were measured after the deposition. At this point, there was a need to make the results comparable. Thus, drawing from both parallel tracks, attention focused on measurements which could be formalized, and a decision to stay with the basic knit patterns was made.

New Methodology development

Overall: Methodology development

During this cluster, the development of the method for evaluating conductive textiles was started, to find a textile-friendly method for evaluating ZnO-samples. The measurements were conducted simultaneously with the development for other textile samples. This cluster took longer than the others, taking roughly a year. It relied on findings from both 'ALD on textile'-, and the 'New ZnO and knowledge'-clusters, of which the latter was the main influence. The resulting method has been written to a publication (Townsend & Mikkonen 2017).

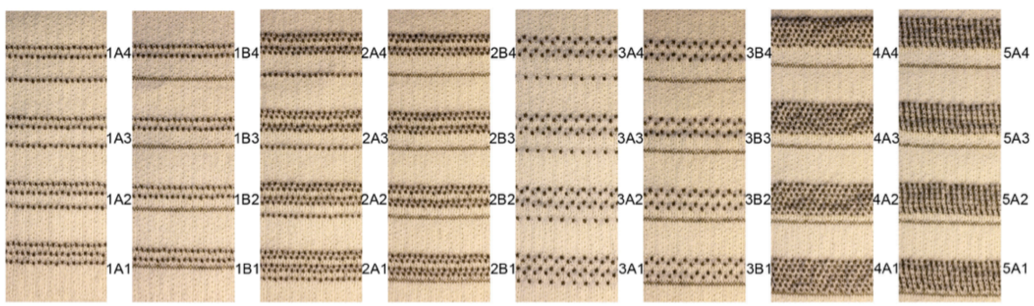


Figure 7. An example of the coded knitted electro-conductive patterns
Source: Townsend & Mikkonen 2017

Textile-specific actions: Methodology development

The 'conflict' of engineering- and design-communication issues during the initial ALD-yarn evaluation was addressed here, specifically attempting to solve the problem of understanding electrical signals in view of textile design. A Stoll CMS-knitting machine was used to create several pattern-wise identical textile samples with different conductive yarns, with one sample shown in Figure 7. These samples were used to create a reference base for ZnO-yarns, as well as to measure the effects of the textile design at the knit-pattern level. The core work of the textile designer was to create a systematic visual comparison map from the measurements, illustrated in Figure 8. This allowed the analysis of the samples to explain the usage and relations of the electrical features and the knit patterns.

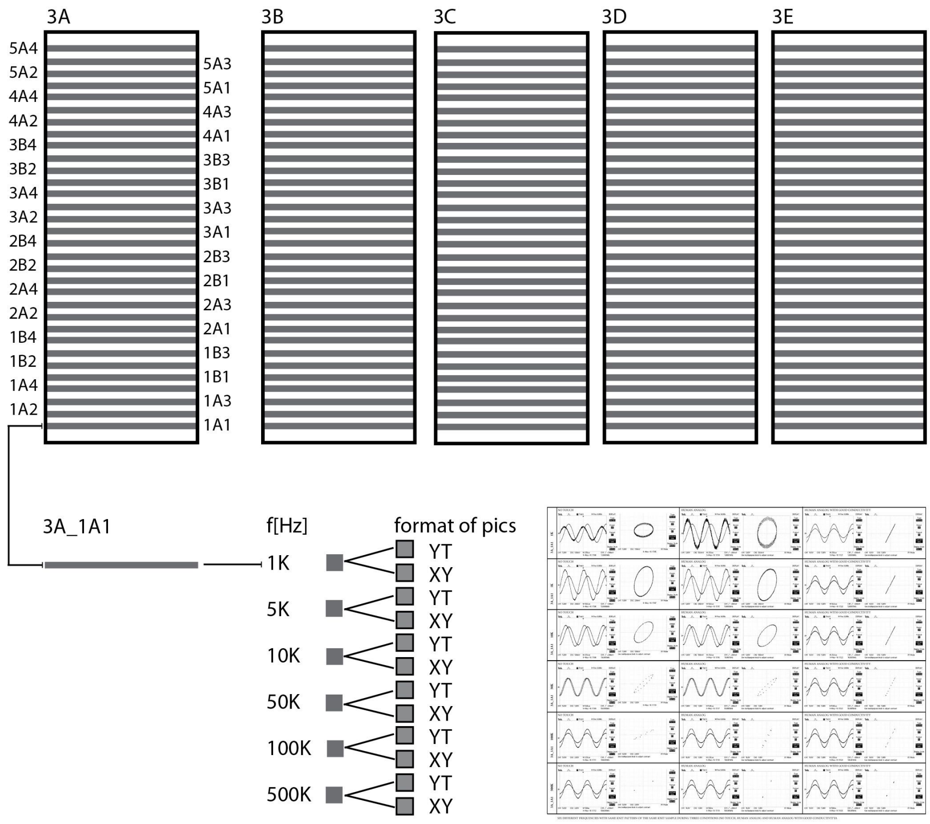
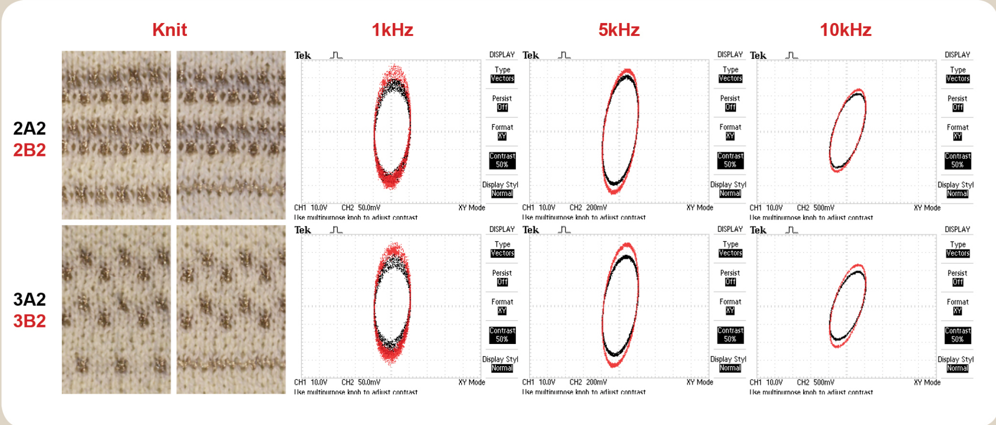


Figure 8. Creating the comparison map

The samples were evaluated using Lissajous-patterns using different frequencies, visualising the properties caused by the conductive yarns, knit-patterns and semiconducting surface oxidation. The oxidation was initially perceived by the textile designer as "something wrong", as the pattern was drastically different from all other measurements. These were then analysed to draw suggestions on how to develop smart textiles using Lissajous-patterns, such as by showing how different textile-patterns exhibit same or similar electrical behaviour. While the textile designer conducted over 3400 measurements independently, the electrical engineer suggested different approaches to the measurements, as well as the oscilloscope use.
This resulted in an approach, which allows the textile designer to evaluate the effects of the changing frequency and to develop functional textile samples independently, while simplifying the usage of the oscilloscope. An example is shown in Figure 9.



Effect of input electrode structures.

The A-knit patterns consist of alternating parallel loops and floats, which are visible and hidden inside the knit respectively, whereas the B-knit pattern is just continuous loops rarely touching. nA2 produces systematically smaller Lissajous-patterns than nB2, while 2A2 produces larger Lissajous-patterns than 3A2. 2B2 and 3B2, on the other hand, produce very similar patterns. The input knits with more electroconductive yarn produce considerably smaller signals, which we suspect is due to the lower overall resistance, and different capacitance due to surface areas.

1kHz

The amplitude differences are difficult to evaluate due to small and noisy signals.

5kHz

The amplitude differences are most visible of all three, being quite pronounced in the 3A/B2 samples. There is also a noticeable tilting in the patterns, suggesting diminished phase difference.

10kHz

The amplitude differences are relatively smaller than in the 5kHz signal, however the signal strength is higher. Furthermore, the phase difference is smallest of the three.

Figure 9. An example of knit-signal correlation
Source: Townsend & Mikkonen 2017

In parallel with the evaluation, “Berlin samples” were constructed. These combine different textile-qualities, towards evaluating how they change. The intent is to create a follow up using more light-weighted samples, to evaluate how the movement- and wrinkle-caused effects could be minimised, counterbalancing the technical measurements. This work is continued in 'connectivity'.

Current and future activities

These describe the current and the future work, which have been planned to follow the findings from the previous clusters. 'Shape change' aims at the experiential use of the actuating materials as a part of a larger system, or as the textile structure itself being the larger system. This is derived both from the initial workshops, and the findings and the work done at the 'sensing and sensorial expression' step. 'Connectivity' focuses on different materials, and how those could be connected in a product level, utilising seams, pockets, etc. depending on the intended use. An example of this creative work is shown in Figure 10., visualising the electric properties of layered textiles. 'Connectivity' draws themes from the initial workshops as well, however it primarily aims to continue from the work done with the method (Townsend & Mikkonen 2017) and to utilise explorations of samples created in 'Methodology development'.

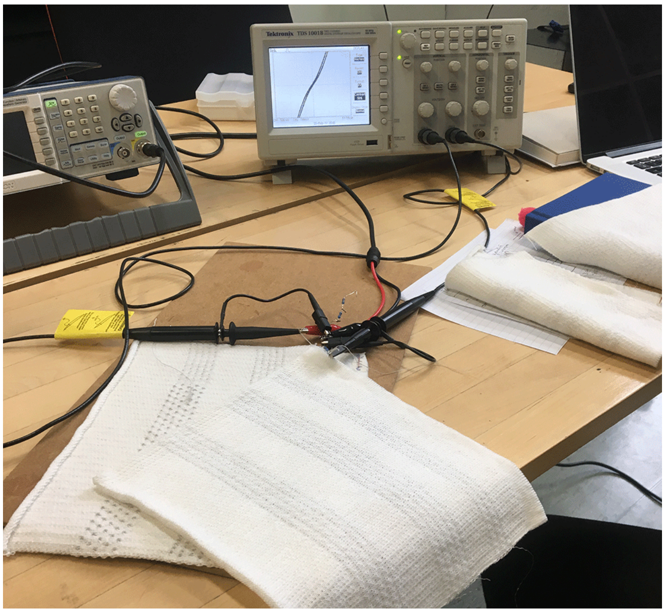


Figure 10. Using the method to evaluate layered textile connectivity

Furthermore, the method has been chosen to the wearable technology and smart textile education at the Aalto University, to get feedback on the method as it is at the moment, and how to further develop it. This course will be held during the Summer 2017. This all leads to the 'applied use', towards a validated model for utilising the method in design. This body of works aims to cover material, sensorial, electrical, visual, tactile, aesthetic, etc. qualities towards directed smart textile design, through the development of functional prototypes.

The method has also been central to the development of a patent application, which is being submitted to evaluation as of this writing. This is expected to lead to the commercialisation of the research findings in select contexts.

Discussion

Our work has resulted in the development of a sensorial material, enabled through human interaction in the process, culminating in a methodology. Therefore, an analysis of the clusters from each of the three aspects is needed.

Sensory aspects of the material

At the beginning, the ZnO-material was not intended for sensorial development, but for energy harvesting from heat differences. The decision to deposit ZnO on a textile substrate was made after the workshops. Due to this decision, thermal experience was explored with a SMA-knitted sleeve, to anticipate on-skin use experience of heat-related wearables. The ZnO-yarn brought in new properties, which initially were missed. However, as a yarn, it has sensorial properties useable in textile design, but was also useable as a sensor.

The following change in the research direction can be seen as an attempt to answer the need to understand properties of the novel yarn, to be able to utilise them (Karana, Pedgley, & Rognoli 2014: Introduction). However, to utilise such yarn requires also knowledge of fundamental, but complex and hierarchical system of fibre-, yarn, and fabric construction and finishing process that interrelate towards the sensory expression of textiles (Behery 2005), and understanding to how each of these 'layers' influence the overall perception and experience when constructed into a product. Thus, the textile designer's sensibility of material directed the selection of the next substrate fibres for ALD. Accordingly, new ZnO was deposited on silk and undyed thinner cotton; to explore textile design related aspects and sensorial (touch) qualities, such as dyeing and weight.

As there was difficulty in utilising the electrical properties for textile-based sensor design, a new method for communicating findings and for designing was needed. This was addressed through systematic knit development and successive measurements. Finally, the method was utilised with the first ZnO-yarns, as a basis for patenting.

Human interaction between research disciplines
Initially, the workshops brought teams together for ideation, however the successive visits to the labs, and efforts to visualise the outcome of the chemical process prompted an atmosphere of openness towards new material explorations. One such point was the UV-fluorescent yarn. Regarding the development of the method, for the textile designer being able to express frustration and discomfort was paramount. This was a clear indicator that current methods were not suitable, enabling the push towards expanding creative possibilities, as discussed by Parsons & Campbell (2004). On the other hand, for the electrical engineer, being able to listen and respond to the frustration was equally important. The openness that the chemists exhibited was seen as a considerable support, as they provided options with which to develop the textile-suitable ZnO-materials, but also suggested and provided ZnO:Al yarns as a reference. Similarly, the support from the School of Electrical Engineering indicated trust in the scientific work done by the design school, but also helped verify the findings. This was in particular with the measurement of the "magic yarn". As most of this work was not at the core of the overall research project, to have time, space and open-minded people to explore the novelty was fundamental. It was seen more important to identify new paths and directions for the future.

Methodology, textile designer's role and creativity
During the process, the textile designer's role gradually changed. While the role of the textile designer was initially to create exemplars based on the technology being developed, it had ranged through electrical engineering and scientific process, to a smart material developer. Regarding the ZnO electrical properties, the engineer initially had a "hunch" based on experience, but the textile designer was not able to fit the findings to the existing knowledge base. Echoing the importance of designer-researcher knowledge (Härkäsalmi and Koskinen 2010), this redirected the overall process away from the exemplars.

The designer's efforts for creating the knit-sample sets, followed by the systematic mapping of the knit-sample signal-data, enabled the method development using a large data set. This is very similar to the representation of "energy density" (Akiwowo et al. 2014:144) used as a "common language", to achieve controlled and repeatable colours in their project (Kane et al. 2015).
The emergent findings, i.e. the semiconducting properties due to surface oxidation, were first seen by the textile designer; having already knowledge about how the visual signal should look, being able to recognise the anomaly was initially through disbelief, and a new experience. By the end of the project, the textile designer was able to use the method and notice novel properties in textile-interaction, prompting the direction towards 'connectivity'. This mirrors the fundamental nature of prototyping and understanding of the new material, as mentioned by Thompson & Ng Yan Ling (2014:203-4), as well as the ability to focus on the creativity and not the method, mentioned by Parsons & Campbell (2004).
What about the end-user needs mentioned by McCann, Hurford, & Martin (2005)? If we take the future textile designers as the end users, then there has been an attempt to fulfil their needs, as well as attempting to bridge the gap between the technologists and the designers. With regards to the ZnO-yarn-based products, the work has just started.

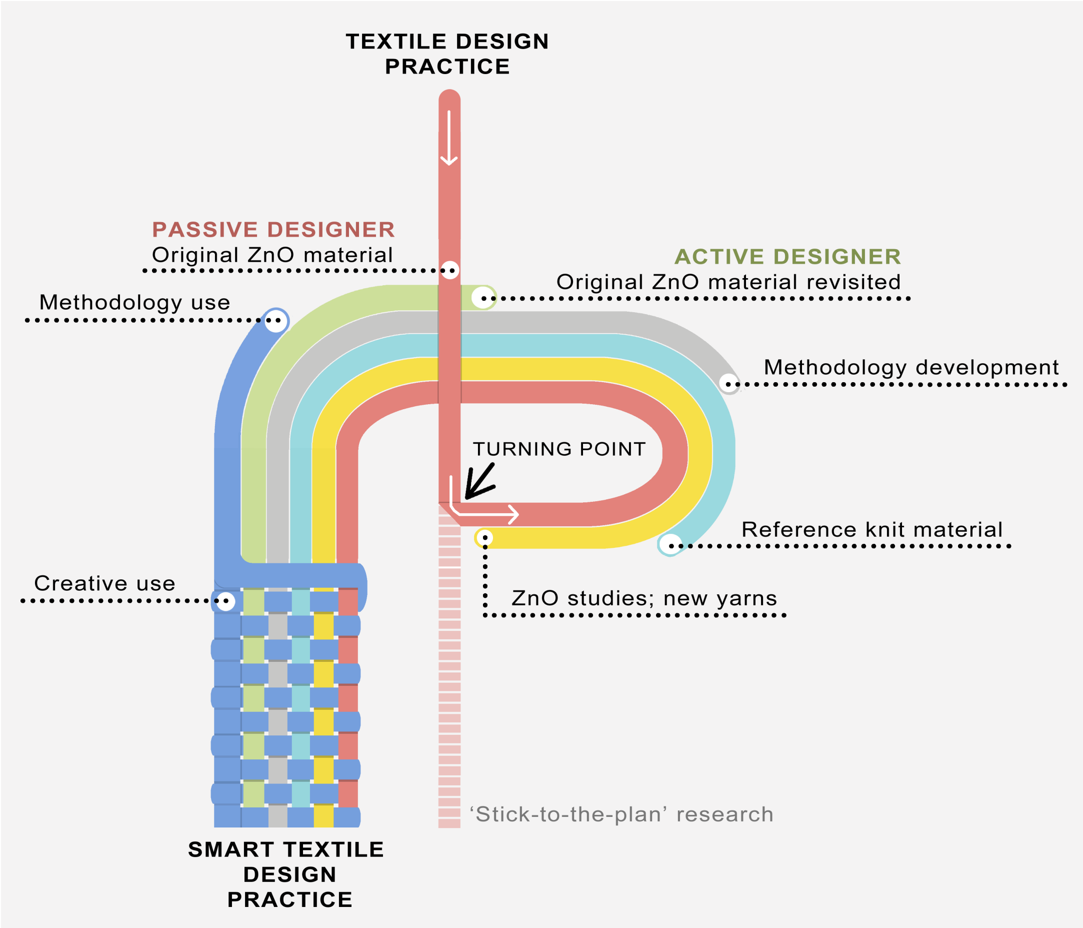


Figure 11. The textile designer path

Concluding remarks

We have described the development path, discussed the directions and the rationale behind them. While we did not follow a predetermined path, instead the findings and reactions to unclear methods led towards an unexpected goal, away from the rigid "stick-to-the-plan" research: the project started as a multidisciplinary project, with the "detour" pushing it to the interdisciplinary domain (Aboelela et al. 2007), paving the way for the transdisciplinary field of smart textiles.

We can summarise this designers path in the Figure 11., focusing on the methodology. After the initial activities, and, textile and yarn selections, the role of the designer became passive at the face of electrical measurements of the initial ZnO samples. Prompting a change, the selection of the new substrates and subsequent testing led to the development of the reference knits. The systematic measurements with the reference knits enabled a verified method, and allowed a new look at the original ZnO samples. After this point, the method allowed examination at relative independence. This was followed with a creative use, where the focus was with the material development, instead of the method use. We also note, that this is very similar to the process, described by Kane et al. (2015). In this light, our overall process demonstrates the accumulated knowledge, contributing to smart textile practice. Regardless, it is our opinion, that if everyone had stayed rigidly on their independent, albeit multidisciplinary paths, the majority of the contributions would have been missed.

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