E-textiles: The intersection of computation and traditional textiles

Interactive Sample Book

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PART 1: INTRODUCTION

1 Introduction

During the past couple of decades, we have seen progress at a revolutionary scale in many fields of science and technology. The invention and constant improvement of electronic chips, computers, the internet, wireless communication, nanotechnology and many other developments, have transformed most of our world and the lives of nearly every human being of our Western society. Looking ahead, the technology of the future seems even more promising. It will have features such as ubiquitousness (Weiser, 1991), ambient intelligence (Punie, 2005), terascale, nanoscale, complexity, cognition and holism (Tao, 2005). The number of systems and information appliances connected to the internet and mobile network are already being counted by the billions[1], with over one trillion ($1x10^9$) operations crossing the internet every minute. As envisioned by Tao (2005) nanotechnology will soon allow us to:

> *"…arrange atoms and molecules inexpensively in most of the ways permitted by physical laws. It will let us make supercomputers that fit on the head of a fiber; impart sensing and actuating mechanisms in micrometer- or nano-structures; allow wireless communication between devices, our body and environments; and make fashionable, intelligent clothing with built-in electronic and photonic functions." (Tao, 2005)*

In the attempt to reach this vision, our understanding of computational technology as large square boxes with screens, keyboards and a multitude of accessories has been challenged by the fast development of current technologies, transforming computation into a 'ubiquitous' resource, an 'intelligence' embedded into things and environments.

Today, we are witnessing the arrival of the fifth paradigm of the human-computer interaction evolution, ubiquitous computing. A paradigmatic shift, which Mark Weiser (1991) and John Seely Brown (1991)[2] around 20 years ago predicted would most likely occur over the years 2005-20. In the era of ubiquitous computing the internet and embedded microprocessors will be everywhere from garments and mobile phones to bus tickets and refrigerators. By letting computation out of the box and into our physical world, embedded into soft and flexible substrates, with materials that possess electromechanical and photonic[3]

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[1] www.gsmworld.com/newsroom/press-releases/2009/2521.htm (11 February 2009)

[2] Xerox engineers Mark Weiser and John Seely Brown first forwarded the idea of 'ubiquitous computing'

[3] According to Encyclopedia Britannica, a *photon* (from Greek *phōs, phōtos,* "light") is an elementary particle. The energy of a photon depends on radiation frequency; there are photons of all energies from high-energy gamma- and X-rays, through visible light, to low-energy infrared and radio waves. All photons travel at the speed of light. They have no electric charge or rest mass; they are field particles that are thought to be the carriers of the electromagnetic field.

functions, potentials for new ways of usage within fields such as military, medicine and industry are predicted to arise[4] (Hassan, 2008). Miniaturization of electronic devices has already changed our lives dramatically, and will most likely continue doing so with further integration of technology, electronics and computing, with other traditional fields such as the textile industry. Koninklijke Philips Electronics (2000) on the topic of integration and harmonisation of techology with other industires, more specifically with fashion, state, that we are talking about a new lifestyle and business revolution. Furthermore it is claimed that in the future of the fashion industry, technology will have to learn to deal with fashion and adapt itself to the needs of users, and not the opposotite way around. This urges the need for the technology and electronics industry to adapt their physical form of an electronic hard shell, to soft, light and flexible form, easily integrated on textiles, adding value to the experience, of a sensory or emotional fulfillment for the user.

So what happens when we combine technology and textiles? The convergence of technology and textile opens new questions about the expressions of technology as it gets a textile surface. It opens questions about the design of new displays for human computer interaction (HCI), which should be close to the natural characteristic of textiles, which are soft and flexible, opposite of the traditional hard and rigid digital displays. On the other hand, the creation of materials with the ability to sense, react and change points towards a world of possibilities for design and application which previously have not been associated with textiles. In that sense what happens to textiles, which are traditionally developed with the purpose of creating static graphical patterns, as computational power makes it possible to work with dynamic patterns and change visual, sonic and even tactile properties (Redstrom, Redstrom, & Maze, 2005).

This requires a new perspective and conceptual view from textile designers to rethink their traditional approaches and techniques of working with textiles and open for new possibilities and opportunities arising from the integration of digital computing, electronics and smart materials.

1.1 Preliminary problem area

As a conclusion to the prior discussion, the research in the pre-analysis stage (conducted prior to the design and implementation stages) will focus on applying a multidisciplinary approach to investigate the development of e-textiles, as part of a bigger concept: ubiquitous computing, as being the intersection of computer interaction, computation, electronics, smart materials and traditional textiles.

[4] Smart materials combined with digital technology are currently under investigation and are applied in the military, the medical and the industrial sector; however it is evident that very soon they will be part of our everyday lives – our living spaces and clothing.

1.2 Framework of the thesis – Interactive Book Sample

The design and implementation part of the thesis is developed in conjunction with a research project called *Interactive Book Sample (Heimdal, 2009).* It is a cross-disciplinary project bringing together designers and engineers exploring the field of electronic textiles. The conceptual idea behind the *Interactive Book Sample* was developed by Elisabeth Heimdal, master student from the Design & Innovation department at the Technical University of Denmark together with the design bureau Diffus (lead by architect Michel Guglielmi and art historian Hanne-Louise Johannesen), based in Copenhagen, Denmark. Collaboration partners for the development of the sample book are textile designer Priya Mani (responsible for the aesthetic design of the samples) and Marija Andonovska, master student from the Medialogy department at Aalborg University-Copenhagen (responsible for the technical design and implementation).

The idea behind the sample book is to function as an inspirational tool for designers (special emphasis is put on textile designers), who wish to start working with some of the possibilities within the area of electronic textiles. As already mentioned the textiles were meant to inspire designers and therefore they had to show *what* they *could* do, rather than *how* they were doing it. When joining the project I took on the task to design *how* the textiles would work. More specifically a large part of my work took focus in the technology which needed to be implemented allowing the smart materials to show *what* they were able to do. The way in which each textile responded to the users' actions was designed by the team's textile engineer. On the other hand, the textile designer together with the design bureau, Diffus held the responsibility of the aesthetic expressions of the sample materials.

For me personally, the development of the sample book was a way to better understanding the technical challenges and opportunities arising from constructing e- textiles. Some of the questions specifically related to the design and implementation of the electronic circuits were:

1. Which electronic components and smart materials should we use for the development of each sample?
2. How should the chosen components and materials be integrated with the textiles?
3. Which techniques should we use to retain the soft and flexible characteristics of the textiles together with hard, rigid and bulky electronics?
4. Should the textiles as an interface reach such an aesthetic form, that they would make the technology disappear from the users' perception?

The task of developing these samples required new and innovative ways of using available materials and technologies making the samples functional, and in the same time preserving the fabric soft, flexible, light and self-contained. Nevertheless these questions were only the base of a bigger perspective related to the integration of technology and new materials, such as textiles and the implications this had on the new materials' interfaces.

1.3 Overview

This thesis consists of three parts guiding the reader through the research, design and implementation and the testing of the sample book. It is concluded with a discussion based on the results from the survey conducted at the end. Each of the following chapters opens with an introduction to uncover the areas, which will be described in details within the section. They are closed with sub-conclusions.

PART 1: INTRODUCTION. Introduction ***(chapter 1)*** reveals the inspiration for this thesis, the preliminary problem area as well as the Interactive Sample Book as a framework within this thesis. Defining Pervasive Concepts ***(chapter 2)*** sets the base for the research area in this thesis. It starts with an overview of the paradigm change in HCI over several decades. It further describes ubiquitous, pervasive, ambient and wearable computing as next step in the development of HCI thus giving the broader perspective in which this project is placed. The chapter ends with presenting the focus area of this thesis which is e-textiles. Current and future wearable Technologies ***(chapter 3)*** details the current and future technologies in the area of wearables and e-textiles including data and energy management technologies, smart materials and soft computing. Related work ***(chapter 4)***, Context and functionality of wearables and e-textiles ***(chapter 5)***, Reflection ***(chapter 6)*** and Defining the problem ***(chapter 7)*** conclude Part 1.

PART 2: DESIGN AND IMPLEMENTATION, includes a description of the Interactive Book Sample, brainstorming and Design specifications ***(Chapter 8)***. This is followed up by Implementation ***(chapter 9)*** covering the choice of physical computing platform and implementation of the interactive samples.

PART 3: METHODOLOGY, SURVEY AND FEEDBACK, wraps up this project with Methodology ***(chapter 10)***, Survey feedback ***(chapter 11)***, Discussion ***(chapter 12)***, and Conclusions ***(chapter 13)***.

1.4 Definitions

The theoretic discourse presented in the thesis is based on terms which many researchers would treat as synonyms, while others define them as slightly different. To clarify the reading, an overview of the different definitions will be presented, with the intent to highlight the differences between. Figure 1 illustrates some of the possible word combinations which have similar meaning.

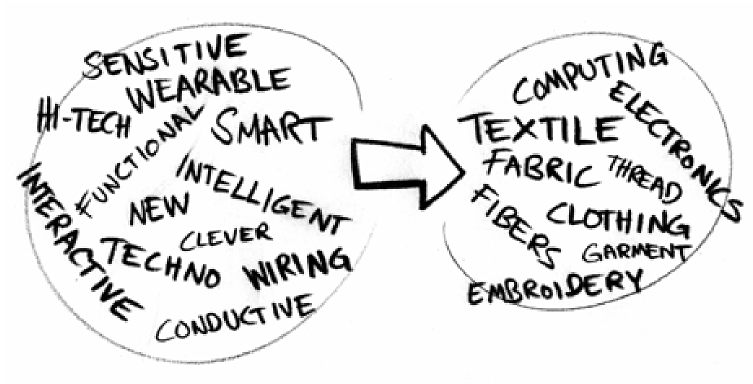

Figure 1 Word combinations

1.4.1 Material/ Fabric/ Textile

Materials - the substance or components of which a thing is made or composed of. Before materials are used as an input for production of manufacturing, they are known as raw materials. For example, cotton is a raw material, which can be processed in a thread, and woven into cloth (semi-finished material). By cutting and sawing the fabric, it is turned into a finished product, a garment.

Textiles – materials are considered to be textile when they consist of drapeable structures that can be processed on textile machinery. Usually textiles are made from of fine and flexible, natural or artificial fibers and threads that have a high length/ diameter ration. The hierarchical structure is made of bundles of fibers, twisted to form yarns, which again are e.g. woven or knitted into fabrics. Ready-made textiles products include ropes, ribbons, fabrics and also three-dimensional products such as clothing (Kirstein, Cottet, Grzyb, & Troster, 2005). In this thesis, links are sometime made to clothing because it is a natural and obvious starting point for textiles, especially if we refer to wearables, where clothing serves as the base to which devices are attached to. When talking about e-textiles reference is also made to other items such as wall hangings, quilts and other fabric-based artifacts.

The words fabric and cloth are used as synonyms for textile; however there is a slight difference in the terms based on textile assembly trade such as tailoring and dressmaking. According to Foss (2007) “textile” refers to any material made of interlacing fibers, while “fabric” refers to any material made through weaving, knitting, crocheting or bonding. “Cloth” refers to a finished piece of fabric that can be used for a purpose such as a bedcover.

1.4.2 Smart Materials/ Intelligent Materials

Many different terms have been used to describe or classify materials and structures that have their own sensors, actuators and computational/ control capabilities and/ or hardware, such as “smart”, “intelligent”, “responsive”, “adaptable”, “sense-able”, etc. As described by Addington & Schodek (2005) in our today’s society “techno-speak” terms seem to come into existence without universal agreement upon their meaning. They state that the word “intelligence” is itself problematic as well as the word “smart”, yet the first should be regarded as higher level that the later. However the engineering and computer science world seem not to make a distinction between the two, presuming that both represent the peak of current technological development. Since there has not been a consensus regarding the use of terminology, several definitions are listed below first for smart materials and later intelligent materials. Based on these definitions and the specific interest area for this report one definition will be chosen.

Smart materials definitions:

> *A smart structure is a system containing multifunctional parts that can perform sensing, control, and actuation; it is a primitive analogue of a biological body. Smart materials are used to construct these smart structures, which can perform both sensing and actuation functions. The ‘‘I.Q.’’ of smart materials is measured in terms of their ‘‘responsiveness’’ to environmental stimuli and their ‘‘agility’’ (Cao, Cudney, & Waser, 1999).*

> *Smart materials can be thought of as materials that replace machines and have the potential to simplify engineering considerably. They integrate the functionality of various separate parts into a single material. This is mechanically efficient because it eliminates the need for parts to be physically interconnected (Berzowska, 2005).*

> *The term “smart” has been used to refer to materials that can sense and respond in a controlled or predicted manner to environmental stimuli, which can be delivered in mechanical, thermal, chemical, magnetic or other forms (Tao, 2001).*

In the book *“Intelligent structures”* (Chong, Liu, & Li, 1990) the authors give a summary of two international workshops - *Smart materials and structure* and *Intelligent materials*, to highlight some of the concepts and definitions debated between the researchers. From all the discussion regarding smart materials, it was concluded that common for all smart materials and structures is:

1. **Sensors:** embedded or intrinsic able to recognize and measure the intensity of stress, strain, thermal, electric, magnetic, chemical and more.

2. **Actuators:** embedded or intrinsic and are able to respond to the stimulus.

3. **Control mechanism:** for controlling the response to the stimulus according to a preretirement relationship. Also capable of selecting response if more than one option is available.

4. **Time and nature of response:** fast response to the stimuli and able to return the material in the original state, as soon as the stimulus is removed.

The listing of the common features of smart materials is very similar to Tao’s (2001) definition, and based on this definition the term smart materials is used throughout this project. Smart materials are also called responsive materials, which in my personal opinion is a better term to describe materials that "remember" configurations and can conform to them when exposed to stimuli from mechanical, thermal, chemical, electrical or magnetic sources. In this thesis, after this section, the word *responsive* will be used instead of *smart*, unless it is a part of a quote.

The following definitions about intelligent materials are presented with the intension to show the slight difference in the definitions about smart and intelligent materials and why sometimes they are mixed and used interchangeably.

Intelligent materials definitions:

> *Intelligent materials may be reasonably defined as materials that possess characteristics close to, and if possible, exceeding those found in bio-materials (Takahashi in Chong, Liu, & Li, 1990)*
>
> *Materials possessed of “intelligence” are such materials that can make the suitable responses by processing the various types of signals, environmental conditions and its objectives. Intelligent materials have a characteristic autonomy, flexible versatility and high adaptability to mankind and nature (Nakatani in Chong, Liu, & Li, 1990)*
>
> *An intelligent material is capable of recognizing appropriate environmental stimuli, processing the information arising from the stimuli and responding to it in an appropriate manner and time frame.*

A further desirable feature is that the material should ideally be self-powered, having energy conversion and storage functions (Wallace, Spinks, & Kane-Maguire, 2003)

The listed definitions are suggesting superiority of intelligent materials over smart materials, especially when talking about characteristics such as “self-powered, high energy conversion and storage functions” of the materials. As stated by Chong, Liu, & Li (1990) intelligence is clearly associate with abstract thought and learning. To date this has not been implemented in any form of an adaptive and sensing material or structure, though scientists are working towards that vision. Intelligent materials are not an area of interest to this research thus it will not be discussed in further details.

2 Defining Pervasive Concepts

> *"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it". (Weiser, 1999)*

Looking back at the last half a century's development within information technology, we can easily be struck with astonishment when thinking of where we stand today, especially when looking at one of information technology's main representatives: the computer. The same goes for the ways in which we humans interact with it. Today, when we refer to "computers" we mean some sort of digital devices calculating ones and zeros through programmed logic, or we even talk of the ubiquitous or invisible computer, but this was not always the case.

2.1 A Brief History of Human-Computer Interaction

In earlier days when the computer:human ratio was one:many it was apparent that people had to adopt geographically should they want to work on one of the few sparse computer, or mainframes as they were called, of the past. In modern times this ratio has changed and we now find ourselves in a situation where there are many, or under normal circumstances at least one computer per human being. In other words we have moved from one:many towards many:one, and it's no longer uncommon having a laptop at work, a pc at home, a PlayStation, MP3 player, mobile phone, car, microwave, television, calculator, DVD player (Saffer, 2007, s. 214-215). Together with the growth in amount of computers, there has also been another major shift in the way we perceive and interact with them. Computers have moved from being single large machines taking up much space towards many smaller machines taking less space. Combining this with the availability of the computer we can argue that our western world's perception and understanding of the computer has undergone four major paradigmatic eras of Human-Computer Interaction (HCI): 1. Electrical ➔ 2. Symbolic ➔ 3. Textual ➔ 4. Graphical (Dourish, 2004, s. 5-11). A fifth paradigm, which is slowly but steadily gaining momentum, is the ubiquitous computing paradigm (see Appendix A for a detailed description of the four paradigms).

2.2 Ubiquitous Computing

The term, ubiquitous computing, describes a futuristic scenario in which computers, embedded in everyday objects such as garments, lamps, chairs, kitchen appliances, windows, doors, shoes, skirts and bags become invisible to the human eye, and if not invisible to the human eye, then at least to the human perception[5]. Looking at the four major paradigms of computing, which dominated the way in which we today describe human-computer interaction during the last 60 years (electrical, symbolic, textual and graphical) it can be argued that ubiquitous computing might well, in a not too distant future, become the fifth dominant paradigm replacing the graphical HCI computing paradigm.

As observed by Mark Weiser, the technological developments had brought with it many improvements in mobile and collaborative technologies combined with greater computing power taking up lesser space. With other words: The time had come to rethink the computer.

Up through the 1980'ies and early 1990'ies most focus on the development of the computer was allocated in thinking "computer" as general-purpose, mainframe, or PC, and it was therefore imperative that several factors had to change before we could truly start calling computing for ubiquitous: 1) Rather than focusing on the computer as a single unit of hardware/software allowing it to execute all kind of different programs, it should be thought of as allocated computing power used for specific tasks. 2) Even though the computer had dramatically dwindled in size, the computer was still very present, as much in the surroundings as in the consciousness of its users. This needed to change as well.

However with the ubiquitous computing research program at XEROX PARC, Mark Weiser argued that the many improvements to low-power devices such as RFID[6] tags and mobile technologies would transform the nature of computers and the way humans interact with them in such a way, which by the time we have reached the year 2020 computing would have become ubiquitous.

We should no longer allow ourselves to be controlled by the artifacts of the past, but rather let humanity regain control. Computers were constantly becoming smaller in size so why not let them totally disappear? Why deal with standalone, visible, multi-purpose and costly machines, when we could instead have many small, interconnected, invisible, single task and low-priced ones? Instead of constantly bringing work to the computer, why not put computation wherever there is the need? Mark Weiser's vision of ubiquitous computing was one of computing by the Inch, Foot and Yard, with computationally

5 www.parc.com/csl/members/weiser (15.02.2009)

6 In its broadest definition, RFID encompasses any system that uses radio frequency to identify an object. - http://www.rfidjournal.com/article/articleview/4819/1/82/ (06.05.2009)

enhanced walls, floors, pens and desks in which the power of computation would no longer be perceived by humans, but stay seamlessly integrated into the environment(Dourish, 2004, s. 28-29).

Another fundamental idea behind the concept of ubiquitous computing was the idea of bringing more senses into use when interacting with the computer. Interacting with the PC was (and still is) very much a question of using eyes and hands. The eyes would then be used for viewing the monitor, while the hands for typing on the keyboard. That was pretty much what interaction with the computer meant until then. Working with ubiquitous computing, responsive textiles and interaction design in general is a step away from that practice, and towards one, where computers are being absorbed without consciously perceived by its users. The users sense the tasks performed by the computer, but not the computer itself. To interact with it doesn't mean being present with one's mind, as interaction would be taking place on a tacit and subconscious level. To be in touch with the computer would no longer require sitting in front of a monitor and keyboard relying on eyes and hands, but instead require a full use of all senses at the times and space when they are needed. With space I naturally mean ours, and not the computer's, world.

Besides ubiquitous computing another well-known scientific approach envisioning human-computer interaction of the future is called virtual reality, or VR. Both approaches are based on similar science-fiction logic, growing in popularity as scientific disciplines from the early 1990s and onwards. Today they both play great roles in computer research and product development. As a direct opposite to virtual reality, ubiquitous computing is not about bringing the humans into the virtual worlds of the computer, but the computer into the real world of the humans(Dourish, 2004, s. 37-38). Ubiquitous computing's approach to interaction, what Mark Weiser referred to as "physical reality", later known as augmented reality, is just about that. The world, as we (users) know it, is the world in which interaction takes place. Virtual reality is just about the opposite. It's about interaction in the computer's world.

What takes the vision of ubiquitous computing beyond mere science-fiction is the common belief in Moore's Law. In 1965 Intel's co-founder Gordon Moore predicted, that the number of transistors on a chip will double about every 2 years[7]. Until now, Moore's Law has held true for more than 40 years, and will most likely continue for at least another 10-15 years, and possibly also more. This implies that in a not too distant future, microprocessors would have become so small and inexpensive that it will be possible embedding them in our surroundings in such a way, that reflecting about their existence would no longer take up our conscious minds. Instead we, as humans, will only feel their presence on a subconscious level through the output they create.

Further supporting this trend in ubiquitous computing are the so-called passive Radio Frequency Identification (RFID) tags, which operate without built-in power sources (Friedemann, 2004). Combining

[7] www.intel.com/technology/mooreslaw - 25.02.2009

the technological advanced we are seeing in microprocessors with RFID and other mobile technologies, the future could very well fit the vision of Mark Weiser. Breaking down all the many inventions of the history of computing, it becomes clear that the trend, for going towards development of smaller, cheaper processors, with integrated sensors as well as wireless communication capabilities is already in place and happening. This evolutionary trend of objects, which steadily are being integrated into our society, is happening all around us. Smart objects, replacing lesser smart objects, are being used in our everyday lives, situating themselves in the “periphery” or “horizon” of our consciousness. As put into words by Mark Weiser:

> *“Such a disappearance is a fundamental consequence not of technology but of human psychology. Whenever people learn something sufficiently well, they cease to be aware of it. When you look at a street sign, for example, you absorb its information without consciously performing the act of reading. Computer scientist, economist and Nobelist Herbert A. Simon calls this phenomenon “compiling; philosopher Michal Polanyi calls it the “tacit dimension”;psychologist J. J. Gibson calls it “visual invariants”; philosopher Hans Georg Gadamer and Martin Heidegger call it the “horizon” and the “ready-to-hand”; John Seely Brown of PARC calls it the “periphery”. All say, in essence, that only when things disappear in a way are we freed to use them without thinking so to focus beyond them on new goals. […] Prototype tabs, pads and boards are just the beginning of ubiquitous computing. The real power of the concept comes not from any one of these devices – it emerges from the interaction of all of them. The hundreds of processors and displays are not a “user interface” like a mouse and windows, just a pleasant and effective “place” to get things done.” (Weiser, 1999)*

The “disappearance” that Mark Weiser is referring to is not as much the physical as much as it is the mental disappearance of the computer. Physical disappearance in this context means the miniaturization of devices including their creative integration in other well-known artifacts such as for example clothing (Streitz, 2006). When talking of mental disappearance, the importance is not on the world itself, but rather on the world as we, humans perceive, and apply meaning to it. In other words this means, that size of the artifacts is not of importance. Whether the computer in a computerized wall is small or big, the wall is nothing more than a wall as long as it’s just the wall being perceived. The same goes for e-textiles. The better we as designers are capable of creatively integrating the electronics, wires, microprocessors (all parts of a modern computer) within the textiles, when perceived, chances are the “e” (standing for “electronic”) disappears from the e-textile, and the only thing perceived is the textile itself.

2.3 Pervasive Computing

The concept pervasive computing is often used synonymously with ubiquitous computing, and more recently *everyware* (Greenfield, 2006). It is used to emphases the invisibility of chips in everyday things and their interconnections, which are creating a bigger network structure. In the context of ubiquitous computing, other words and terms closely related in meaning to "invisibility" are: "transparency" (Barkhuus, 2002), "periphery", "horizon", and "ready-to-hand"(Weiser, 1999). According to characterization by the National Institute for standards and Technology (Flanagan, 2001) pervasive computing is:

i. *numerous, casually accessible, often invisible computing devices*
ii. *frequently mobile or embedded in the environment*
iii. *connected to an increasingly ubiquitous network structure*

At the turn of the millennium Intel announced the technology turn:

> *"Computing, not computers will characterize the next year of the computer age. The critical focus in the very near future will be on ubiquitous access to pervasive and largely invisible computing resources. A continuum of information processing devices ranging from microscopic embedded devices to giant sever farms will be woven together with a communication fabric that integrates all of today's networks with networks of the future. Adaptive software will be self-organizing, self-configuring, robust, and renewable. At every level and in every conceivable environment, computing will be fully integrated with our daily lives."*(McCullough, 2004)

Many leading research organizations are exploring pervasive computing. To name a few, IBM with their living laboratory Planet Blue are creating technology-assisted immersive environment for individuals and teams to easily create, learn, use and share knowledge with few limitations or disruptions, regardless of physical location or context[8]. Another similar project is Aura developed by Carnegie Mellon University's Human Computer Interaction Institute (HCII) which goal is to provide each user with an invisible halo of computing and information services that persists regardless of location[9]. Project Oxygen at the Massachusetts Institute of Technology (MIT) presented a similar picture of the future as Intel:

> *"In the future, computation will be human –centered. It will be freely available everywhere, like batteries and power sockets, or oxygen in the air we breathe. It will enter the human world, handling our goals and needs and helping us to do more while doing less. We will not need to carry our own devices around with us. Instead, configurable generic devices, either handheld or embedded in the environment, will bring computation to us, whenever we need it and wherever*

[8] http://www.research.ibm.com/compsci/planetblue.html (22.04.2009)

[9] http://www.cs.cmu.edu/~aura/ (26.05.2009)

we might be. As we interact with these "anonymous" devices, they will adopt our information personalities. They will respect our desires for privacy and security. We won't have to type, click, or learn new computer jargon. Instead, we'll communicate naturally, using speech and gestures that describe our intent ("send this to Harry" or "print that picture on the nearest color printer"), and leave it to the computer to carry out our will."[10]

These projects are striving towards a future where technology is removed from the consciousness of the users and towards a seamless integration of applications with information, which will be available no matter in which physical location or context the users are. Thus the design challenge in pervasive computing is as much an interaction design challenge, as focus is put on making the interaction with these applications as transparent as possible.

2.4 Ambient Intelligence

"It is the vision of a world in which technology, in the form of small but powerful silicon chips, will be integrated into almost everything around us, from where it will create an environment that is sensitive to the presence of people and responsive to their needs. An ambient intelligence environment will be capable of greeting us when we get home, or judging our mood and adjusting our environment to reflect it or soothe it."[11]

In the late 1990s, built upon the idea of ubiquitous computing, ambient intelligence was presented as a new and more complex scenario of the future. Ambient intelligence describes a futuristic world in which an internet of things, a network organism consisting of billions of devices is communicating intelligently with itself and its environment. Their main purpose being serving human beings, not in a master-servant logic as described by Mark Weiser (1999), where smart, single task devices stay hidden from our conscious minds, but rather as a vision of the future information society, were people and intelligent devices interact with each other and with the environment in an intuitive fashion, with one of the main differences between the ideas of ubiquitous computing and ambient intelligence being the level of intelligence of the devices we use: Smart versus intelligent.

The idea and vision describing the interconnected world as one of ambient intelligence was first proposed by Philips Research in 1999, almost a decade after Mark Weiser's visionary foundations in ubiquitous computing. The work in ambient intelligence was then further developed in collaboration with the

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[10] http://oxygen.lcs.mit.edu/Overview.html (22.03.2009)

[11] www.research.philips.com/technologies/projects/ami/background.html (23.03.2009)

Massachusetts Institute of Technology (MIT), and the IST Advisory Group (ISTAG), a group of experts from industry and academia advising the European Union(Punie, 2005). Philips' own research in ambient intelligence was, and still is, made through its HomeLab project. Besides being a home, HomeLab is also a laboratory. It has real living spaces in which technology is hidden from the users suggesting that ambient intelligence is not as much about technology as it is about its users. As advocated by Philips it will not be ambient intelligence, which will shape the future of ordinary people. It will be the ordinary people shaping the future of ambient intelligence. A lot of the research conducted by Philips is therefore aimed at classical ethnographic studies, in which experimental psychologists, engineers as well as scientists participate[12].

As with ubiquitous computing, technology is still operating in the background, and is connected in a wireless and self-configuring network of devices constantly communicating. Technology is no longer viewed as just smart but more as intelligent and capable of being aware, and taking care of people's needs, besides responding intelligently to spoken words and gestures. Additionally the technology surrounding our daily lives will be able to engage in intelligent conversations and dialogue with their human counterparts. The core ideas behind ambient intelligence are human-centered computing, user-friendliness, user empowerment and the support of human interaction. In order to materialize these visionary concepts into reality, ambient intelligence technologies need to be designed by looking into the very micro universe of the potential users (Punie, 2005). We need to understand how our minds think, in order to make the technologies invisible to them. Transparency is as much a question of mental as it is of physical disappearance (Streitz, 2006).

With the increased bandwidth in both fixed and wireless communication networks, breakthroughs in mobile technology, RFID tags, the predictability of Moore's Law, together with the speed and availability of modern day devices, we can already now begin to envision such an internet of things surrounding the periphery of our minds. Further supporting this vision are the constant improvements in computer software development with first generation intelligent agents already a reality. Examples of existing agents are the many different kinds of email alert informing users about incoming offers, news and event changes. Whether we are simply searching for a book title, a DVD movie or searching for a job, agents are also there to help us making our everyday lives simpler, often without us noticing their presence, but intuitively accepting their assistance for making a better choice. These many forms of fast paced technological progress in all kind of devices has contributed to the shaping of the ambient intelligence vision, allowing us to perceive the future as one of intelligent interaction between humans and computers. Both ubiquitous computing and ambient intelligence are no longer believed to be pure science-fiction, but

[12] www.research.philips.com/technologies/projects/ami/background.html (23.04.2009)

facts of our futuristic lives, and in many cases lives of today, most often without us being aware of their presence.

Since Mark Weiser lay out his foundations for ubiquitous computing many things have changed, many of them, perhaps quite foreseeable even in the late 1980s: Most members of the Western world have access to an internet connection, a computer, a mobile phone. Technology has become remarkably cheaper and more available. On the other hand, what Mark Weiser could not statistically predict at his time, was the complexity of the software, which was going to be built in the future. In Mark Weiser's vision of ubiquitous computing he was referring to smart devices performing single task operations. Today we are talking about intelligent devices performing complex operations such as engaging into conversations with the users. Computers, in the ambient intelligence vision, are not dummy devices, awaiting instructions, hidden behind the wall. They are the walls proactively engaging us.

2.4.1 The Invisible Computer

As with ubiquitous computing the essence in ambient intelligence is the idea of the computer disappearing from our awareness, and moving into the "horizon" or "periphery" of our consciousness. In other words, the computer becomes invisibly embedded into the many objects we use in our everyday lives or transparent (Barkhuus, 2002). To do so it needs to be either creatively integrated into the objects or made transparent in another way, so that the tasks that we perform, and the pleasures that we enjoy will move to the front, while the computer moves to the background of our attention. First though we need to learn to both feel trust and security in an Orwellian society in which we know we are being observed, perhaps not directly by governments as pictured in George Orwell's dystopian novel "1984", but by the technologies surrounding us. There will be stages of early adaptation, in which humans will get accommodated one by one to the technologies of the future, allowing them to steadily create invisible networks of interconnected devices. Ultimately the technologies would have become domesticated, meaning we, as society, have started taking them for granted, reaching a state of mind in which devices have become unnoticed extensions of the self (Punie, 2005). Once the devices are no longer there to be perceived, the meaning we will create through the use of them will be the meaning of the use per se. The computer is gone from the equation, and the only thing left is its functionality ubiquitously available providing new forms of interaction, creating what we could perhaps also label as the fifth HCI-paradigm of calmness. Technology is no longer obtrusive. Its main goal is calming (Streitz, 2006).

Before reaching as far as envisioning a world of ubiquitous computing and ambient intelligence, first we need to understand in detail how people interact with the devices surrounding us. We need to understand our cultural and ethnographic backgrounds and we need to know the context in which each of our activities is taking place. Designing for transparency is not as much designing objects as it is designing user experiences, and the meaning users put into the objects through the context in which they are being used.

2.5 Wearable Computing

As described in the previous section ubiquitous means that computing is seemingly present everywhere. Wearables are true extensions of the idea of incorporating ubiquitous computing in everyday objects *(Seymour, 2009)*.

> *"A wearable computer is a computer that is subsumed into the personal space of the user, controlled by the user, and has both operational and interactional constancy, i.e. is always on and always accessible."* (Mann, 1998)

From an electronics and photonics science and technology perspective Tao (2005) describes a *wearable* as a device that generates, transmits, modulates and detects electronics and photonics and it *"is always attached to a person and is comfortable and easy to keep and use. In other words, it is apparel with unobtrusively built-in electronic and photonic functions*".

Historically the idea of wearables is quite old, dating back to the early 1960s. Mathematicians Edward O. Thorp and Claude Shannon, the latter also known as "the father of information theory", in 1961 constructed a cigarette-pack sized analog computer with four buttons, which indicated the speed of a roulette wheel. Via radio waves, it then transmitted the predicted results to a miniature speaker hidden in the bidder's ear. The device was tested in Las Vegas and revealed five years.

Since then, many researchers have experimented with devices in the area of general purpose wearable computing. In the 1981 Steve Mann, professor at MIT (Massachusetts Institute of Technology) developed a backpack mounted computer to control his photographic equipment. Mann has been an active researcher in the field of wearable computing and he has developed many head and wrist mounted displays and cameras. In 1994 he became especially know for developing the Wearable Wireless Webcam.

In mid 1990s Philips made a survey as part of their Future Project to get a better understanding on the impact technologies had on peoples' lives and to gather information which will lead their new approach to future lifestyle to meet the needs of the consumer. The research indicated that consumers wanted to be connected and equipped with tools for every possible event, without the inconvenience to carry around multiple devices (Koninklijke Philips Electronics, 2000).The consumers demanded smaller devices with more functionallity, associating miniaturisation with sofistication. However, they found out that consumers were required to carry several devices each of them satisfying a limited number of functions. These functions were designed based on the companies' interpretation of the customers' needs and anticipating use in a way that rarely matched actual practice. The mobile phones, the PDAs, the personal audio devices, the portable computers they all contained the same functions and components, yet were not transferable. In many cases these electronic devices created frustration with their complicated and inaccessible functionality, their inability to share components and communicate to one another remotely. Besides being inefficient, they were also inelegant and far from enabling and enhancing the consumers' lifestyles, they were in fact becoming a hindrance (Koninklijke Philips Electronics, 2000). In the summer of 1997 Philips gathered a multi-disciplinary team to explore the field of electronic fashion with goals based on an initial investigation in the area wearable electronics.

In 2000 Industrial Clothing Design Plus released the first commercial range of wearable electronics together with Philips NV, Levis Strauss and designer Massimo Osti. One example is the jacket designed for urban commuters that 'live in the fast lane', convenient for light travelling or even empty-handed, while one is still being able to retain full and direct access to information and maximize on-the-move communication capability (Koninklijke Philips Electronics, 2000). When dressing the user selects the devices one needs based for the scheduled activities ahead and plugs them to the clothing he or she has chosen to wear. The electronic devices are small signal function modules. The earpiece is comfortable and can be used all day, and a speech device is integrated in the inside of the jacket. The display is flexible and integrated in the fabric as well as the key pad. Similar garments were produced to meet the needs of other target groups besides the urban commuters, who were also considered early adopters of wearable solutions such as clubbers; active sportspeople who wear high-performance sportswear for extreme sports, e.g. snowboarders, climbers, runners, cyclists, etc.; and financial district workers who work on the move. For their needs garments were designed equipped with variety of technologies such as embedded MP3 player and global service mobile (GSM), using unified remote control; biometric sensors for monitoring the body; motion detector monitor, warning display; temperature sensors and heating materials; phone functionality with wireless connections that control sound and light, sampling and scanning functions, electroluminescent digital display, LCD and small lightweight camera.

The examples mentioned above use conventional technology and represent the first steps towards integrating electronics in commercial wearable electronics. However there are not many successful commercial products and one of the main reasons is that the current available technologies, electronics and materials are not suitable for commercial products. Many designers are troubled by the fact that a lot of the responsive textiles that they encountered are more technical than poetic.

Nevertheless a lot of research and funding has been devoted to these new emerging technologies for wearables. As processing power is doubling at light speed, components are miniaturizing, alternative energies are becoming more accessible the visions of wearables and ubiquitous computing are looking more like it could become a reality in a not too distant future.

The idea behind wearables is that people should be freed from the trouble of joggling between multiple devices. The vision is that users won't have to wear anything but their clothes or accessories, with embedded general purpose wearable, with information and functionality available when needed in extremely broad and varied sets of environments. Thus clothing would become the medium, used by designers to take advantage of more parts of the body, possibly the entire surface area, creating controls, which are easy to use and mechanisms that can respond in any give situation(Koninklijke Philips Electronics, 2000). As a result new ways of interaction is needed, as screens will not be an optimal approach of interacting with the digital world or the way the digital world reacts to our actions. Communication through voice, touch and gestures has been suggested(Saffer, 2007).

Wearable technologies combine together a number of disciplines such as electrical engineering, physical computing, wireless communication networks and interaction design. Depending on the context in which a wearable will be used expert knowledge could also be necessary from a number of other disciplines. Thus designing innovative, multifunctional and appealing wearables require a multidisciplinary collaboration between software engineers, interaction designers, consumer trend analysis, textile designers and socio-cultural researchers. As a starting point designers of wearables use clothes and accessories, as things most people have on them most of the time. Clothing and accessories are used as platforms for embedding wearable and wireless technologies. Combined together many opportunities arise in the world of wearables. However, there are many challenges as well, not only when designing the functionalities but also when creating the form. As wearables are meant to be worn, a particular attention has to be paid to make them durable, light weight, stylish, self-contained, unobtrusive and sustainable.

2.5.1 Electronic Textiles

E-textiles is a research area which is part of wearable computing. In fact many refer to electronic textiles as wearables, as they are intended to be used for the creation of interactive clothing and accessories. However e- textiles can also be used for designing interactive spaces, such as implementing e- textiles in sensitive carpets, curtains, walls and so on.

The research area of electronic–textiles (e-textiles) is a fairly new one, which is closely related to wearable computing, but still in many ways has its own distinct field. According to Buechley (2006) wearable technology investigates technologies, which are portable and attached to or carried on the body, where e-textiles have a slight different focus such as exploring electronics and computational technology, which are imbedded into textiles. More specifically e- textiles are textile substrates that integrate capabilities for sensing (biometric or environmental), communication, power transmission as well interconnection technology, that allow sensors or processors to be networked together within a fabric, usually by incorporating conductive yarns, instead of wires to allow electricity to flow and thereby allow little bits of computation to occur on the textile (Berzowska, In the Shadow of the Cyborg, 2005), (Seymour, 2009). Hence, the ultimate goal for researchers of e-textiles is to develop technologies, which are entirely fabric based and even though some progress has been made in that direction (Bonderover & Wagner, 2004) (Lee & Subramanian, 2005), this vision is still far from being feasible. Thus designers are forced to integrate traditional electronics like microcontrollers, light emitting diodes (LEDs) or electroluminicent (EL) materials into their design.

In the attempt to merge computation, textile and responsive materials enabling new ways of computationally-mediated interactions with the environments designers Berzowska and Bromley (2007) suggest moving away from traditional electronics and going towards the exploration of emergent materials, which make it possible to enable physical computation for the body and personal spaces within the frame of what they coin *soft computation*. The term describes the design of digital and electronic technology that uses responsive materials such as conductive yarns and fabrics, active materials and flexible and fabric sensors, small microcontrollers and electronic components to allow the construction of electronic circuits on soft substrates.

It is seen that e-textile researchers strive towards building things that are soft and flexible as often seen in traditional clothing, while at the same time putting in practice Weiser's (1999) ideas about unobtrusive technologies, which "weave themselves into the fabric of life", some researchers and designers are working on redesigning current electronics and using technology not only as a functional tool but also as a material one.

Buechley et al. (2008) work forcuses on making computation soft and beautiful and with that in mind they developed an e-textile constuction kit for which a number of traditional electronic and computational elements were redesinged, to make them attractive and easy to attach on textiles. The goal was to make the process of desining e-textiles more accessable and deserible to individuals outside the techical academia, such as artists, textile designers, fashion desingers and hobbyists. This example showed that it was possible to make the harsh, unattractive shell of electronics beautiful and inspirational, while not completely hidding or interweaving the electronic materials into the fibers of the textiles.

Thus much of this thesis is inspired by the research work of Berzowska and Buechley as well as other designers and design studious that are exploring the engineering and aesthetic challenges and opportunities emerging from the design and computation space around e-textiles.

2.6 Sub – conclusion

This chapter gaves an overview of the different pervasive concepts setting the bases on which this thesis investigation is building upon. From the concept of ubiquitous computing, we narrowed down to the area of wearable computing and more specifically e-textiles, which will be in focus in the coming chapters. What follows is as an overview of the current and future technologies of wearables and e-textiles. As e-textiles are part of the broader area of wearable computing, much of their enabling technologies are overlapping and they share many of same benefits and challenges.

3 Current and future technologies for wearables and e-textiles

The technologies embedded in wearables influence the comfort, wearability and aesthetics. According to Tao (2005) (Figure 2) a typical system configuration of a wearables includes several basic functions such as: *interface*, *communication*, *data management*, *energy management* and *integrated circuits*. This classification is based on general purpose wearable computers.

A similar classification is presented by Seymour (2009) with focus on fashionable wearables, a combination of aesthetic as well as functional pieces . Thus most common technological components used to develop fashionable wearables are: *interfaces* (connectors, wires, and antennas), *microcontrollers*, *inputs* (sensors), *outputs* (actuators), *software*, *energy* (batteries, solar panels), and *materials* (interactive or reactive materials, enhanced textiles).

Both classifications are overlapping each other, but for the purpose of this thesis they will be combined and all the concepts explained, with emphases on e-textiles. The project examples used in this section, supporting the theory are related to wearable textile technology already available on the market or projects currently being developed in research labs around the world showing promising results in becoming future technologies. The diversification of the project concepts goes from being very functional and practical towards more expressive and artistic.

3.1 Inputs

To obtain information for wearable devices components such as sensors are often used, for instance, environmental sensors, antennas, global positioning system receivers, sound sensors and cameras. Such sensors can be divided on active and passive(Langenhove & Hertleer, 2004)(Seymour, 2009). Active inputs are controlled by a user via a tactile or acoustic feedback system, which provides an intuitive interaction with the garment. Passive inputs collect biometric data from the human body as well as environmental data collected via wireless transmission system. The data is captured and further processed usually using a microprocessor. The table below provides suggestions for the type of inputs wearable systems can collect from a person or the environment.

Origin	Inputs
Person	Voice, visuals, pressure, bend, motion, biometric data, proximity, orientation, displacement, smell, acceleration
Environment	Temperature, light, sound, visuals, humidity, smoke, micro particles

Figure 2 - Suggestions types of inputs that a wearable system can collect

3.1.1 Input Interfaces

The most common way for a user to interact with a device these days, involves the use of buttons, keyboards and screens, as they are proven to be easy to learn, implement and use with few mistakes. Fabric- based interfaces using keyboards and buttons are most common for wearables. They are usually designed from either multilayered woven circuits or polymer systems (Tao, 2005). At the dawn of ubiquitous computing environments, people will need to engage with many different devices with built-in microprocessors and sensors. As wearable devices become more complex, a need for more complex interfaces arises. People want more options on their devices, they want everything, but they also want them with the maximum of easy, freedom and comfort. This requires new ways of interaction, such as user engagement through voice, touch and gestures. The devices of the future will have no faces(Saffer, 2007). They will implement more intuitive ways of interaction.

Voice recognition - Voice-controlled interfaces are currently most common on phones. However there are few drawbacks in the technology. It is difficult to create voice-controlled interfaces in public spaces, from both technical and design perspective, when the system should always listen for a command. In this case, incorrect processing of information is possible due to large influence of background noise. How will the system know to differentiate between a command and a background noise is a design challenge that yet needs to be answered. Furthermore, the current voice recognition technology has a problem distinguishing between different people’s voice and additionally, it requires more processing power then previous technologies. Leading researchers believe these obstacles will be overcome as technology advances, predicting that in a very near future we will interact with voice – controlled devices and environments.

Gesture recognition - As devices gain better awareness of the movement of the human body through technologies such as Global Positioning System (GPS) sensors and sudden – motion sensors (SMSs), gesture recognition as a way of human interaction with devices is becoming even more achievable. Indeed, there are devices such as mobile phones equipped with tilt motion sensors, so that users can, for example, "pour" media data from their phone to another device (Dachselt & Buchholz, 2009). Donneaud (2007) created a large textile interface for playing electronic music. Figure 3 illustrates the textile interface that is constructed of two conductive fabrics which are fixed on a frame each one weaved with conductive threads in a different direction.

Figure 3 – Textile XY: interface for playing electronic music

When the performer presses any point of this textile, the two fabrics connect and the current electrical value is sent to the computer. This textile interface is flexibility and transparency, involving the whole body through choreographic movements in the musical interpretation, thus allowing the performer to explore the textile interface by look, touch and gesture.

Presence recognition - Person's presence is another way of interaction with a system. Present-activated systems are one of the central research points for ambient intelligent environments. The main design and technical challenge here is what determines if the system should react to the presence of a person, how it should react and how fast this reaction should be after a change has been detected.

3.2 Outputs

There are a variety of output devices or materials which activate in wearables as a result of computation triggered by input data. Many outputs can stimulate any of the five the senses of the wearer or his audience. For example, shape memory alloy can change the silhouette of a fabric presenting a visual experience for an audience and a tactile experience for the wearer. The table below provides an overview of possible outputs to address specific senses.

Senses	Outputs
Visual	LEDs, EL wires, displays, photochromic ink, thermocromic ink, E-ink
Sound	Speakers, buzzers
Touch	Shape memory wires, conductive yarns, conductive fabric, motors/actuators
Smell, Taste	Scent capsules

Figure 4 - Overview of possible outputs that address specific senses

3.3 Communication technologies

For electronic components to truly become part of bigger interactive systems they need to be connected in order to exchange information. Wires, cables, antennas and connectors are most common physical components used to connect electronics together. Wired connections are secure and practical in many cases, but they can cause inflexibility and add to the weight of the system. On the other hand, wireless connections increase flexibility and the lightness of the system, but increase its complexity.

The advances in wireless technologies have played a significant role in the development of wearables and e-textiles, reducing the number of devices attached to a system, simplifying its construction as well as minimizing the size. According to Seymour(2009) some of the most common wireless communication and location based systems are: UMTS (Universal Mobil Telecommunication System), GPRS (General Packet Radio Service), GSM (Global System for Mobile Communication), GPS (Global Positioning System), Cell Triangulation, WIFI, Bluetooth, IR (Infrared) and PAN (Personal Area Network). These communication systems can be further subdivided to *long- range* or *short range communications*(Tao, 2005), if the transfer of information is between two or more users via the internet or a network protocol or between two or more wearable devices worn by a user, respectfully.

3.3.1 Long-range communications

The long-range communication technologies advanced during the mobile revolution. All portable devices such as mobile phones, PDAs, MP3 players use radio frequencies to enable communication. From the list above the following communication systems: UMTS, GPRS, GSM, GPS, cell triangulation, WIFI are long-range. GSM is the communication system currently most suitable for voice transmission, as well as for data and files transmission at 9.6 kbps. For transfer of pictures and video a third-generation (3G) wireless system is also available, with the capacity of 384 kbps. GPS and cell triangulation is suitable for navigation purposes. The variety of communication systems opens many possibilities for wearable devices and the exchange of information.

3.3.2 Short-range communications

Short-range communication for wearables is a research area that still needs to be developed. Some of the approaches considered for implementation in wearables are wiring, infrared, Bluetooth technology, WIFI, Personal Area Network (PAN) and Fabric Area Network (FAN). Even though they have some disadvantages, they show promising results as future technologies embedded in devices and textiles.

Embedding wires in garments is cumbersome and constrictive, and therefore not adequate. For infrared to be effective it requires direct lines of sight, which is not practical and difficult to implement on different devices worn on the body. Bluetooth technology is widely used, with an open wireless communication protocol which ensures connection between several devices within a short communication range (10 m), overcoming problems of synchronization. This technology is embedded in a range of products (such as smart phones, headsets, mouse, keyboards, printers and game consoles) and has many applications in situations where low-bandwidth communication is required. Bluetooth devices can interact independently of the user, as well as advertise services they provide, thus making this network more secure than other types, as more of the security, network address and permission configuration can be automated. This also provides an easier access to services for the users. WIFI (also called “wireless Ethernet”) uses the same radio frequency as the Bluetooth, but with higher power, resulting with a stronger connection. The users have the advantage to move around within a broad coverage area and still be connected to the network, through a variety of WIFI enabled devices such as laptops, smart phones, PDAs.

From a collaboration research project in 1996 between MIT Media Lab and IBM Almaden Research Center a new wireless technology emerged called the Personal Area Network (PAN) also referred to it as Body Area Network. The technology is considered the backbone of wearable technology, allowing exchange of digital information, power and control signals within the user's personal space. PAN takes advantage of the natural electrical conductivity of the human body combined with a transmitter embedded with a microchip, to create an external electric field that passes an incredibly tiny current (1 billionth of an amp- 1 nanoamp) through the body, used to transmit data (IBM, 1996). As a comparison, the electrical field created by running a comb through hair is more than 1000 times greater than the current required for PAN technology to be functional. The technology is still being refined but researchers see great potential in PAN, as an effective and cost-efficient communication network. Passing of simple data between electronic devices carried by two people would be easier than ever, such as exchanging business cards via a handshake. This scenario as fascinating as it sounds also imposes many security issues, because touching a person with a PAN is like tapping a phone line (Tao, 2005).

In 2001 Hum proposed a wireless communication infrastructure to enable networking and sensing on clothing called the Fabric Area Network (FAN)[13]. The technology promises to solve some of the problems Bluetooth and GSM are facing, regarding the public concern of health hazards from the increased amount of emissions in the body from these sources of radiation. The new and innovative method, in which the technology architecture is designed, uses radio frequency (RF) fields for data communication and powering, restricted only to the surface of the clothing thus eliminating radiation into the body. More specifically, the technology uses multiple radio frequency identification FRID links, which have been used in the industry for years for tagging and tracking products. Even though the technology is being promoted

[13] The architecture includes a central base station controlling several short-range antennas positioned on various parts of the clothing, such as on the sleeves, the back of the shirt, the shirt pockets, the trouser pockets and other locations. The antennas are used as communication nodes connected to chips embedded in personal items like wallet, watch, pen, shoes and other accessories. To have various functionalities in clothing Hum (2001) proposes multilayer fabric, with a sensor layer, an actuator layer, an audio layer, a video layer, an interface layer, a storage layer, a memory layer, a motion layer and more. Thus each layer will have a unique functionality. For example, the sensor layer will have both physical and biological wireless sensor monitoring the condition of the human body and collecting data, which are sampled and collected in the central base station for processing. This layering model provides options for building various custom-made intelligent clothing that are pushing the limits for pervasive and ubiquitous applications and services.

as emission-save, low-cost and easy to maintain, it still has much more development it needs to undergo before such networking and sensing clothing can be considered for mass production.

The technologies described above such as GSM, GPS, WIFI and Bluetooth are already widely used as part of wearable devices. Since, they have been proven to be stable communicational systems and well developed; attempts have been made in the research community for their implementation in computational and smart textiles. However, these technologies were not initially designed for integration in clothing and accessories and thus researchers are modifying and perfecting these wireless networks to meet the requirements that currently established communication systems, cannot fulfill. For that reason, wireless networks such as PAN and FAN were originally designed and are still investigated.

3.4 Data management technologies and integrated circuits

The storing and processing of data in wearables is carried out in integrated circuits (IC), microprocessors or microcontroller. Integrated circuits are miniaturized electronic circuits which are mostly manufactured from silicon because of its superior semi conductive properties. However silicon is not flexible and therefore ICs are not very suitable for incorporating them on clothing. Developing ICs from conductive or semi-conductive polymeric[14] materials can be of great importance for wearable electronics since these materials are flexible, lightweight, and strong and of low production cost (Rossi, Capri, Lorussi, Scilingo, Tognetti, & Paradiso, 2005). Their down side is that they are not as efficient as silicon, and thus scientists are looking into developing electronics in the near future that will be a combination of both silicon and conductive polymers which will be complimenting each other.

Among the most advanced integrated circuits there are the microprocessors which are the heart of any normal computer. Also known as the CPUs (Central Processing Units), they present complete computation engines fabricated on single chips. The microprocessor performs many functions some of which are executing a stored set of instructions carrying out user defined tasks as well as carrying the ability to access external memory chips to both read and write data from and to the memory. From the architecture of the microprocessors, more specialized processing devices were developed, such as microcontrollers.

[14] Having the properties of a polymer

A microcontroller is a single-chip computer, which is embedded in many everyday products and therefore it is also called “embedded controller”. If a product has buttons and a digital display, most likely it also has a programmable microcontroller that provides a real-time response to events in the embedded system they are controlling. Such automatically controlled devices, often consumer products, are remote controls, cell phones, office machines, appliances, toys and many more.

Even though microcontrollers are “small computers”, they still have many things in common to desktop computers or large mainframe computers. All computers have a CPU which executes many different programs. In the case of microcontrollers the CPU executes a single program and thus they are known as “single purpose computers”. Also microcontrollers have a hard disk, a RAM (random-access memory) and inputs and outputs, which are all combined on a single microchip. Other characteristics common for a majority of microcontrollers, besides being embedded inside other devices dedicated to run specific single task programs, are that they come as low-power devices, small and at low cost, which is of great importance for wearable e-textiles. While some embedded systems are very sophisticated, many of those implemented in wearable e-textiles have minimal requirements for memory and program length, with no operating system and low software complexity. The actual processor used in the microcontrollers can vary widely, where ones choice when designing interactive applications depends on the context in which the embedded system will be used. The programs running on the microcontrollers can be stand-alone or can communicate with the software running on other external devices, preferably through a wireless network.

3.5 Energy management technologies

One of the biggest problems in wearable and integrated electronic technology is power and the quest for alternative energy sources is essential. Today batteries in the form of AA batteries or lithium batteries are the most common source of energy utilized for running embedded systems and processing of captured data through a microcontroller. However their life span is limited and designers of wearables will have to find new and improved solutions to acquire the needed energy, either making it long lasting or easy to recharge on the move. At the same time the energy source must become light and discreet, which currently is the heaviest part of wearables.

The need for alternative sources of power is rising as the demand for greater design freedom in creating light, flexible and reliable wearable e-textile is increasing. Researchers see a potential in an alternative source of power based on the miniaturization of fuel cell technology. The way fuel cells generate electrical power is similar to batteries, as they convert the chemical energy of a given type of fuel (e.g. hydrogen and oxygen) into electrical energy. They have longer lives than batteries of similar size since oxygen does not need to be stored, only hydrogen in metal hydrides (Larminie & Dicks, 2003). Before 2010 Toshiba is planning to launch the first commercial direct methanol fuel cell-based (DMFC) batteries for cell phones and laptops.

In the beginning of 2009 researchers from the University of Illinois claimed they have developed the smallest working fuel cell, with dimensions 3 mm x 3 mm x 1 mm and it is made from four layers: a water reservoir, a thin membrane, a chamber of metal hydride, and an assembly of electrodes (Heine, 2009). Scientists claim that with the capacity of 0.7 volts and a 0.1 milliamp current for about 30 hours the mini battery can be used to run simple electronics. Researches see a great potential in fuel cell technology as it is considered to be a clean, efficient and silent technology, nevertheless the main hurdles preventing commercial introduction is high cost, lack of durability, high system complexity and lack of fuel infrastructure (Bruijn, 2005).

Another interesting alternative energy source for intelligent clothing is to harvest the kinetic energy from the human movement or the fluctuations in body temperature. Even though this energy is very minimal to drive wearable technology and can only be measured in microwatts, it is still a research field that attracts attention. Some research has been done in piezoelectric materials, which creates charge when mechanically stressed, thus inserting them on shoes, walking power can be harnessed (Tao, 2005).

Other forms of power supply are utilizing photovoltaic cells which are gathering the energy of the sun, allowing a sustainable approach to wearable technology. There are many examples of products that are incorporating solar panels onto the surface of wearable e-textiles, using thin film printed on flexible surfaces such as plastics; however the efficiency of this alternative energy source still needs to be improved.

3.6 Responsive Materials

Responsive materials represent a new generation of fibers, fabrics and articles, which are able to react in a predetermined way when exposed to stimuli, such as mechanical, electrical, chemical, thermal, magnetic and optical. They are reactive and dynamic and they have the ability to change color, shape and size in response to their environment. For many years researchers have devoted their work in developing responsive materials such as shape memory materials, chromic materials, micro and nanomaterial and piezoelectric materials.

By constantly improving and incorporating responsive materials in the development of light and flexible electronic components, conductive and semi-conductive materials, such as conductive polymers, conductive threads, yarns, coatings and inks, are receiving widespread attention. They are less dynamic then smart textiles but equally important in realizing fashionable, desirable, lightweight, soft and wireless computational textiles.

The following section gives an overview of conductive and responsive materials that are currently most used in wearable computational textiles.

Conductive fabrics and textiles are plated or woven with metallic elements such as silver, nickel, tin, copper, and aluminum. There are many different fabrics with various textures, looks and conductivity and few samples are illustrated in Figure 5 (left), those are: electronylon, electronylon nickel, clearmesh, softmesh, electrolycra and steelcloth. All these textiles show amazing electrical properties, with low surface resistance[15], which can be used for making flexible and soft electrical circuits within garments or other products, pressure and position-sensing systems. They are lightweight, flexible, durable, soft and washable (some) and can be sewn like traditional textiles, which makes them a great replacement for wires in computational garments.

Figure 5 – Conductive fabrics (left); Different types of conductive threads (middle and right)

[15] Surface resistance, measured in Ohms per square, is the resistance of the material to the flow of electrical current between opposite sides of its surface. In materials with low electrical resistance, electrons easily flow through or across the surface of the material (Pakhcyan, 2008).

Conductive threads and yarns have a similar purpose to wires and that is to create conductive paths from one point to another. However, unlike wires they are flexible and can be sewn, woven or embroidered onto textile, allowing for soft circuits to be created. They contain metallic elements such as stainless steel or silver, with nylon or polyester as base fiber. Commercially available conductive threads usually vary in the resistance and the thickness of the thread. Figure 5 (middle and right) illustrates few commercially available threads. Since they are conductive when working with them, one has to take all the precautions as when using uncoated electric wire or a metallic surface without insulation. Conductive threads and yarns offer alternative ways of connecting electronics on soft and flexible textiles medium as well offering traditional textile manufacturing techniques for creating computational garments.

Conductive coatings are used to convert traditional textiles into electrically conductive materials. The coatings can be applied to different types of traditional fibers, yarns and fabrics, without changing their flexibility, density and handling.

Conductive ink is an ink that conducts electricity, providing new ways of printing or drawing circuits. This special ink can be applied to textile and other substrates. Since wearable e–textiles require great flexibility, conductive inks are become more interesting for designers and developers in this area. Conductive inks contain powdered metals such as carbon, copper or silver mixed with traditional inks.

Shape memory alloys (SMA or muscle wire) are composed of two or more metals usually nickel and titanium, combination also known as Nitinol. These wires, usually of very small diameter, have the capacity to actuate when heated and to return to their original shape when cooled. Their capacity to flex or contract is up to 5% and it is a result of dynamic changes in their internal structure generated by an electric current. Some SMA wires can be “programmed” (heated at a transition temperature) into a particular shape for ex. zigzag or coiled. They can remember the form, to which they return when cooled. SMAs are used for triggering movement, have been woven in textiles or can make fabrics shrink or curl in wearable e-textiles applications. Long before SMAs were introduced to wearable e-textile projects, they have been used in many different areas, like electronics, robotics, medicine, automotive industry and appliances. SMAs are more and more becoming an interesting material for designers working on interdisciplinary projects across the fields of computation, technology, science, design and art. They explore how new ways of combining SMAs with computation can aid the design of responsive garments, objects and spaces and provide more meaningful interfaces.

Piezoelectric materials have the ability to generate electrical charge when exposed to mechanical stress (sound, vibration, force or motion). Piezoelectric materials exhibit reversible effect because they can produce electrical charge when subjected to stress and also they can generate stress when an electrical field is applied. Therefore the materials can be used both as sensors and actuators. Piezoelectric materials can serve as excellent environmental sensors, but the number of interesting applications in wearable e-textiles is even greater if they are coupled with other sensors, for ex. solar cells where they can be used to convert light to sound, motion or vibration.

Chromic materials are those that radiate, erase or just change the color based on the induction caused by external stimuli. They are also known as non- emissive “active materials” (Berzowska & Bromley, Soft computation through conductive materials , 2007). The classification of chromic materials depends on the stimuli affecting them. Some of the most know are photochromic and thermochromic materials. Most of the color changing phenomena (photochromism, thermochromism, electrochromism, piezochromism etc.) are reversible.

Photochromic (inks and dyes) are materials that react to light as an external stimulus. They are typically available in powdered crystals of ultraviolet (UV) sensitive pigments that need to be dissolved in an ink for application. Once the material is exposed to sunlight, blacklight or other UV source it will change from clear to colored state. When the UV source is removed they revert to their original state. They can be applied on various media, including textile, paper, plastic, wood and glass and can be used to create dynamic patterns that change in accordance to light variations in their surroundings.

Thermochromic inks are heat sensitive materials. They are made from various compounds that need to dissolve in the appropriate ink type for application. When exposed to a specific temperature they change from one color to another of from color to translucent. Thermochromic inks can be classified to three types, *low* - react to cold, *body* – react to body heat, touch and breath and *high* – react to hot liquids and air. They have the ability to infinitely shift color and with that create dynamic patterns on various substrates, including textiles.

Nanomaterials and microfibers have been the subject of enormous interest, over the past decades. They are materials fabricated on a molecular level. The technology is aimed at manipulating the structure of materials on atomic, molecular and nano[16] level in a precise and controlled manner to create products or byproducts with specially engineered characteristics. Scientists use the prefix nano to denote a factor of 10^{-9} or one-billionth. One nanometer is one-billionth meter which is about 100,000 times smaller than the diameter of a single human hair (Qian & Hinestroza, 2004).

Many believe that the future development of many areas of our lives lie in nanotechnology, which fundamentals are based on the fact that properties of substances can change when their size is reduces to the nanometer range. The technology will be used in fabricating nanomachies, nanelectronics and other nanodevices to improve existing products and to create many new ones. Nanotechnology will also

[16] The prefix *nano* comes from the Greek word “nanos” which means dwarf.

have a great impact on textiles, being able to transform the molecular structure of the fibers and create fabrics that offer unsurpassed performance and comfort. The technology is likely to revolutionize wearable e-textiles, by not only developing very small and flexible electronic devices embedded in textile substrates, but it will go even further, ultimately having the electronic devices and system becoming the fabric itself. Researchers have already started to develop transistors in yarn form and to make conductive, carbon nanotube[17]-modified cotton yarn (Lee & Subramanian, 2005) (Qian & Hinestroza, 2004). This will give smart textiles remarkable functionalities yet simple feel and handling, similar to traditional fabrics. There are a great number of studies dedicated on textile modification on nanomaterials carried with nanoparticles, for adding metal and semiconductor nanoparticles to fabrics such as fashionably glittering colors, antimicrobial function, UV protection, wrinkle resistance, and anti-odor function (Kotov, 2008). Inevitably nanomaterials and microfibers will lead the development for fast, simple, robust, low-cost, and readily scalable process for making e-textiles.

3.7 Sub conclusion

The previous section presented technologies which are commercially available, as well as research that is currently being conducted and perfected. Understanding how far wearable and e-textile technologies have come, it is easier to imagine the possibilities and challenges which will arrive when working with them. The following section will give an over of few projects within the area of wearable and e-textiles.

[17] According to Britannica carbon nanotubes are nanometer-scale tube-like structures, which have remarkable electronic, mechanical, and chemical properties. Depending on their specific diameter and the bonding arrangement of their carbon atoms, nanotubes exhibit either metallic or semiconducting behavior.

4 Related Work

During research the following inspirational and stimulating projects were found, some approaching the field of wearable computing and e-textiles from purely abstract and stylish nature to more functional pieces focused on the technical potential, combining the ‘hard’ technology with ‘soft’ textile. Some of the projects successfully hide the technology, creating soft and flexible displays, switches, sensors or buttons by only implementing layers of conductive fabrics and threads, other celebrate the beauty of electronics, creatively incorporating it in the design. There are several reasons for choosing these projects. Some are chosen for the innovating techniques in which electronics, computation, responsive materials and textiles are utilized, others for presenting new expressive potentials in e- textiles as dynamic displays as wells are for their potential as tools for social and emotional communication and interaction.

Figure 6 - Solar Vintage (2007) by Elena Corchero & Distance Lab

Elena Corchero has designed the collection *Solar Vintage* [18]of solar powered accessories for the eco – fashion-minded. The pieces are charged during the day, when used outdoors and in the evening they become ambient decorative lights for the home. All the electronic components like solar cells, resistors, and LEDs are integrated directly into the textile and wired together into working circuits using conductive thread. This collection aims not to hide technology but to disguise it in a beautiful and stylistic way.

Leah Buechley [19]work focuses on making computation soft and beautiful, and on creating artifacts that engage and empower a broad range of people. She has designed a number of bracelets since 2005 that

[18] http://www.elenacorchero.com

[19] http://web.media.mit.edu/~leah/

are woven on a traditional bead loom out of beads, conductive thread and surface mound LEDs, in a 5x10 display matrix that can be programmed with animations like cellular automata and scrolling text. According to Buechley the recent bracelets are as thin and flexible as traditional beaded jewelry, controlled with surface mount electronics and soft circuitry and powered with flexible Lithium-ion batteries. They also function as motion-sensing, communicating wearable displays (older versions were displays only). Each new bracelet contains an accelerometer that senses wrist movement and a Bluetooth module for wireless communication. They can interact with laptops, PDAs and cell phones as well as each other and other wearables.

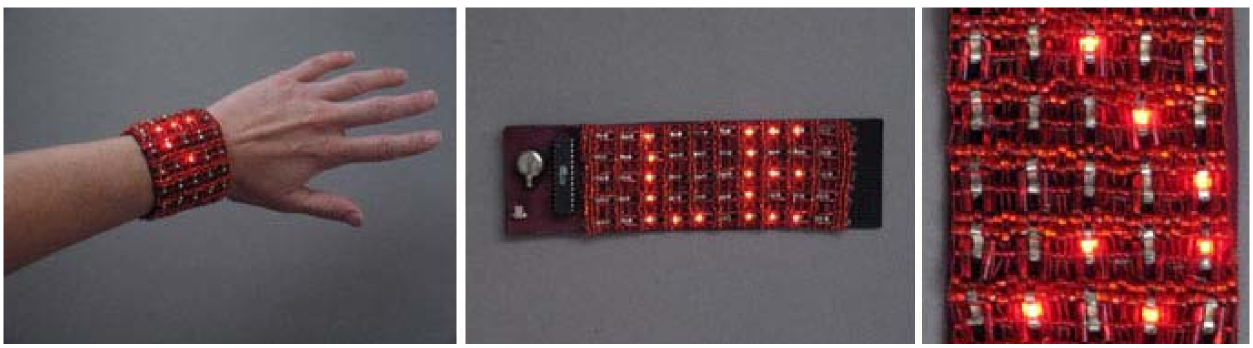

Figure 7 - Wearable display bracelet by Leah Buechley (2005 - ongoing)

She has also designed a shirt as programmable wearable, which acts as a low-resolution display. It is programmed with cellular automation and text animations, which the wearer can set through an embedded IR receiver connected with a PDA.

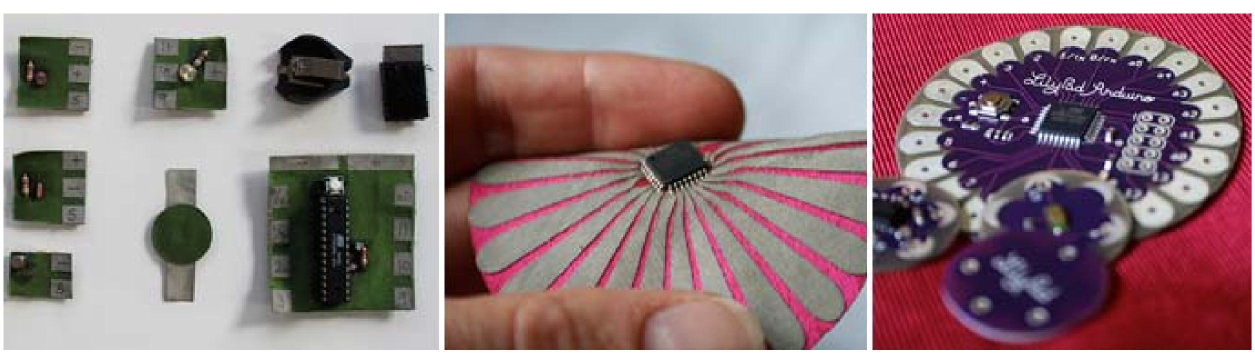

Figure 8 – One of the first versions of the LilyPad Kit from 2006 (left); fabric PCB (middle); commercial version from 2007

However her most significant contribution to the research field of wearables and e-textiles is her project *LilyPad Arduino*[20], a collection of microcontroller, sensor and actuator pieces, which are modified traditional electronics that can easily be stitched on a fabric. Each board is constructed of fabric-based iron-on circuits or “fabric PCBs”, build with a laser-cut technique from conductive cloth and a heat activated adhesive. Every input/output tab of each module is attached to a conductive fabric petal on the flower-shaped boards. The resulting circuits are soft, flexible, multi-layered and can be soldered as well as sewn. The different pieces of the collection can be sewn together with conductive thread and then programmed with the Arduino software. The commercial version of the LilyPad collection replicates the design of the soft version on mass produceable traditional circuit boards. This hard version sacrifices some of the aesthetic and sensual qualities of the original, but makes creative experimentation with e-textiles accessible to designers, artists, DIY enthusiasts etc.

Figure 9 - Interactive pillows (2001-2002, 2004)

Christina von Dorrien (Carmen Systems) et al, started the project *Interactive Pillows* [21]in 2001, which is based on the idea to develop new devices for interpersonal communication with focus on aesthetic, social and emotional aspects. The concept was communication between distant loved ones that involved picking –up and hugging a pair of pillows. When one is hugged, the other will light up and change its aesthetical expression. If the other person hugs theirs back, its pair will warm and start to glow as well. The technical solution is designed using electroluminescent wires, ‘hugging sensor’ (which basically is two layers of aluminum foil divided with foam, which has inch-size whole, this way when the pillows are squeezed, the two layers of aluminum touch and contact is created, thus the electrical circuit is closed), microprocessor and radio frequency module. The pillows currently are communicating using radio

[20] http://web.media.mit.edu/~leah/LilyPad/

[21] http://www.tii.se/reform/projects/itextile/pillow.html

frequency, however this is not enough for long distances, thus the developers of these pillows propose wireless communication via the internet, or potentially via a mobile phone as an alternative.

XS Labs[22] is a research studio founded by Joanna Berzowska with focus on innovation in the fields of electronic textiles and wearable computing. They have created many complex textiles with electronic properties, where one of the most interesting projects is *Kukkia and Vilkas*. *Kukkia* is an expressive and behavioral kinetic sculpture in a form of a flower that slowly opens and closes over time, like a caress. The felt and silk petals provide relative rigidity and integrate stitched Nitanol wire, which enables the slow, organic movement. *Vilkas* is a dress with a kinetic hemline on the right side that rises over a 30 second interval. It is constructed of a heavy felt and uses a very light yellow cotton element that wrinkles as a result of the heated Nitanol wires that pull the cloth together. The effect is not a result of any external or internal input, but is programmed to rise autonomously.

Figure 10 - Projects with Nitanol wire from the research studio XS Lab (2005)

Hannah Perner –Wilson and Mika Satomi[23] are exploring the realm of technology, bring a spirit of humor to technology and a twisted criticism towards the stereotypes it creates. They are lead by the idea that technology is to be hacked and modified to fit everyone's needs and desires. Their project *Massage me* is a wearable massage interface for a video game. It requires two people, one to wear the jacket and receive the massage and another to play the game thereby massaging the wearer. The player is equally a gamer and a massager. The massage jacket is turned into a gamepad, by making soft flexible buttons on the back, made from layers of conductive fabric. The materials used are: stretch conductive fabric, foam, neoprene, silicone, iron-on, shielded wire, thread, game controller and came console (Playstation).

[22] http://www.xslabs.net/kukkia&vilkas/index.php

[23] http://massage-me.at/

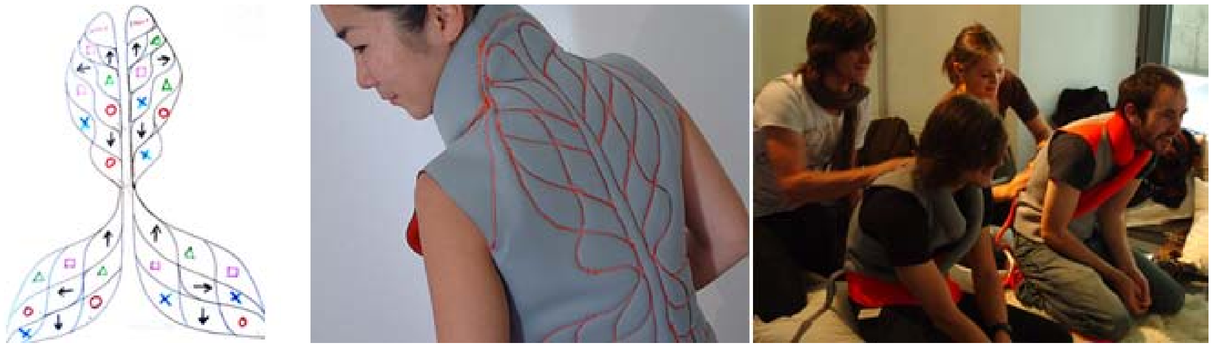

Figure 11 - ***Massage me*** **gamepad (2007)**

Phillips is one of the leading companies in the area of wearable technology and ambient intelligence. There latest commercial product *Phillips Lumalive*[24] is unique and revolutionary, allowing ordinary textiles to light up with vivid colorful animations and messages. The product is designed of 14x14 pixel LED canvas connected to a player, which is based on a microprocessor and a 128 Mbytes of content storage flash memory. This enables the canvas to display up to 10 min of non-repeating animated graphic sequence at 40 images per second. A USB connection allows the user to upload animated graphics, scrolling text messages or moving images, to the player from a personal computer. Phillips states that the product is flexible and soft as traditional textiles.

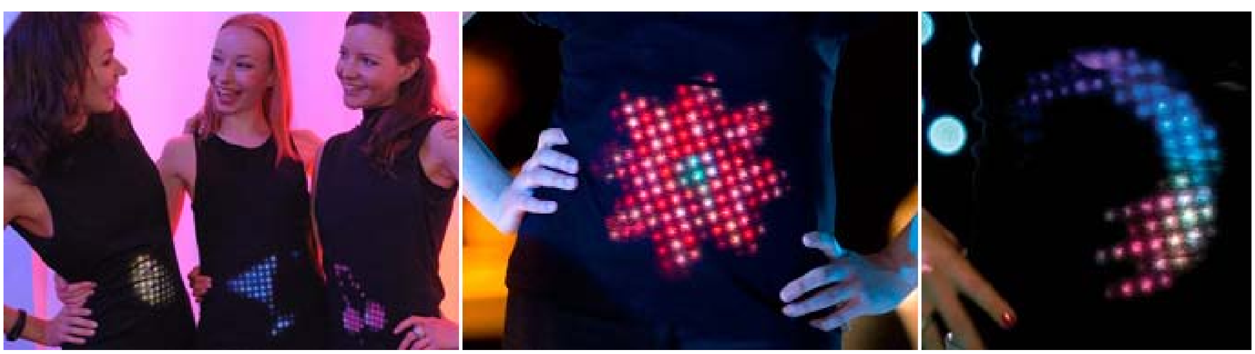

Figure 12 - Phillips Lumalive products (2009)

[24] http://www.lumalive.com

4.1 Sub-conclusion

The presented projects and many others I have come across during the research were not only inspirational but also gave an understanding of the potentials that current of-the-shelf electronics and available materials have, when combining textiles and computation. Many of the selected projects have been designed during the last few years of which many are still ongoing projects, going through several iterations of prototyping, while others like the LilyPad Arduino and Phillips Lumalive have already been commercialized. Nevertheless, they all capture the imagination in their various proposals on the future meaning and purpose of technology combined with textiles, whether that is clothing, accessories, or various types of textile decorations and artifacts, as powerful and dynamic medium for conveying messages and emotions.

5 Context and Functionality of Wearables and E-textiles

Naturally, textiles have more than just physical functions such as protection and concealment, they also bear cultural connotation (Barnard, 2002). As part of the cultural functions, clothing has social and psychological implication related to the individual expression, communication, social or economic status, political or religious affiliation. By embedding technology to textiles those functions are enhanced and new ones have been defined. They are defined by the context in which they are intended to be used.

Looking back, early wearables were functional but uncomfortable to wear and unpleasant for the eye. Since then the tendency is towards ease–of-use, light, comfortable wearables, as people want devices that are unobtrusive and convenient. At the same time newest generation of wearable devices implement even more advanced technology that can integrate sensing, actuating, electronic and power functions. Furthermore these devices have the computational power to collect, store and share information with other devices or display them to the environment. Thus wearables are becoming mobile, dynamic canvas upon which one can display and process this information.

The levels between expressiveness and functionality can vary depending on the context in which the wearables are used. The following table (Seymour, 2009) gives an overview of the concepts.

← 1 — 2 — 3 →

Expressivness — Functionality

1. High fashion wearables are very expressive and functionality is less important. Aesthetics and style are the focus.
2. Wearables that have a defined function but also strive to be stylish as well. For example sportswear requires this duality.
3. Wearables that focus on functionality. In workwear there is a very limited space for personal expression, directed by pre-defined functionalities and restrictions.

Figure 13 - Levels of expressiveness vs. functionality

Looking at this table, on one side of the spectrum, we can place the military research which is focusing on providing pragmatic applications of smart clothing for camouflage or healing wounded soldiers, or medical research, which is focused on health monitoring, rehabilitation, health assistance and sports medicine. On the other end are creative designers and artists who work in the area of reactive textiles, which are adaptable to various environments as well as to its users. Industries such as telecommunication and fashion are pursuing the vision of clothing that can express people´s individuality, needs and desires or augment social dynamics through the use and displays of aggregate social information(Berzowska, Electronic textiles: Wearable Computers,Reactive fashion and Soft Computation, 2005).

In this thesis the focus is on the area of wearable computing and e-textiles which can be used as expressive medium. This refers to the design of clothing, accessories or other textile objects from our everyday surroundings, which can be used as interfaces to the exterior mediated though digital technology (Marchall McLuhan in Seymour, 2009). Here they combine both functional and expressive elements, which create powerful potentail of becoming transmitters and receivers of enriched human emotions, experience and meaning.

6 Reflection

The technological advances in every domain of our lives, the rise of ubiquous computing and the effortless way of accesing information, is constantly changing our needs and requirments. In the developed world, we are constantly striving towars satisfyting the higher order needs (meta needs) from Maslow's hierarhy of needs which include cognitive, aesthetic, self –actualisation and self-transcendent(Baurley, Intercation Desing in Smart Textiles Clothing and Applications, 2005). Products have always created some sensoril experince, but as Baurley(2005) states intelligent objects and enviromnets as envisioned with the ubiqutious computing will engage in a higher level of meeting our needs for sensory and emotional fulfilment, personal expression, and social interaction. Wearable computing and electrnic textiles are striving towards becoming mediums for such rich sensorial experiences. Experiences are created though our interaction with objects that simulate our sences. Wright(Baurley, Intercation Desing in Smart Textiles Clothing and Applications, 2005) states: *"An experience is described in terms of its structure, our sensory and emotional engagement, and the actions and events over time and in a place. Experiences do not present themselves to us ready-made, people actively construct them trough a process of sense making. This process consists of our expectations, responses, interpretations and reflections of an experince."* There is a shift in the design community towards experiental design focusing more on the values of experience that users have with the products that eventually will become ubiquitous in all areas of the design practice. For designers to achive this they need to investigate how people use, engage and feel about things and places(Baurley, Intercation Desing in Smart Textiles Clothing and Applications, 2005).

From the research in current and future technologies presented in the previous chapters, it is evident that technologies used in wearable computing and e-textiles are still not meeting the needs for full sensorial experience. As Berzowska (2005) states, it is ironic that although current wearable technologies and computing are very powerful, they are still not very wearable. Though research is advancing and making great progress in new materials and mobile digital technologies, many of these devices still remain hard plastic, metal, and silicon. They are heavy and angular and thus many commercial designers (especially textile designers) are resistant towards taking digital technology and computing into consideration. Seymour (2009) in her book *Fashionable Technology* gives a comprehensive collection of the most recent projects in the area of wearables and e-textile that combine aesthetics and style with functional technology. As she states many of the projects are conceptual in nature. This confirms the need for adaptation of technology, electronics and computation to textiles. It proves that even though there are many interesting and innovative ways how people could remotely interact with each other and the environment, the reality is that current technology needs much improvement for these ideas to develop in commercial products and part of the urban context. Research in the field of wearables has to move the technology and the electronic industry towards building lighter, more flexible and more powerful computational devices, which can be carried or worn with no inconvenience for the end user, allowing them to only explore the benefits and create new experiences through the products.

Furthermore, technology not only has to adapt its physical form but also functionality has to evolve to prove its importance for integration. Referring back to Seymour (2009) only few projects presented are actually commercial products (sports wearables). Some of these products are developed by Nike, which is a company with a reputation for designing sportswear based on the emotion of sport as inspiration, while their positive attitude to new technology and ideas provide the innovation. This brings us to another interesting point. Wearables and e-textiles have to be designed to meet the needs of specific target groups. Researchers may see great potentials in computation and textiles merging into a new medium for expression, but the majority of people are still not clear about the advantages of wearable computing. They are skeptical about the idea, which presents integration of computational devices with textiles. Ordinary people might worry how to handle yet another device, now embedded on our clothing, with which we have uniquely intimate relationship with. This presents the need not only for a physical transformation of the enabling technology but also a conceptual one. End-users need to be convinced of the benefits that this new combination of technology, responsive materials and textiles brings to their lives; that it is not intruding in their privacy, that it is save and robust, that they can use it easily and effortlessly. It is known that engineers and computer scientists on their own cannot achieve the creation of desirable and functional wearables and e-textiles, just by adding more processing power and more options onto the mobile or portable devices. Thus a joint effort of interaction designers, textile and fashion designers and electronic engineers is needed, where the mix of disciplines will develop a creative tension based on cultural antagonism between engineering and design problem-solving methodologies. This brings us to the target group of traditional textile designers who will also have to change their mindset in regard to digital technology and computation and their integration with textiles.

> *"Textiles are the oldest and most important materials we use in our everyday lives, the things we wear and to furnish our surrounding, chances are that our understanding will be significantly transformed given the implications of current technological advance… the real challenge will come from new areas such as 'smart textiles'. In this area, the creation of materials with the ability to sense, react and change points towards a future of uses, expressions and design possibilities not previously associated with textiles. … As textiles expend beyond traditional textiles design, arts, craft and fashion into electronics, computation and even nanotechnology, what might once have seemed a rather 'traditional' material transforms one of the most innovative areas of new design materials."* (Redstrom, Redstrom, & Maze, 2005)

Thus it is the technology that will transform textiles in interactive interfaces and mediators of information. Textiles will no longer be static or unrisponisive, as its dynamic properties will have the potential to exibit components of our identity in new and interesting ways. As a result, we will witness a new generation of textiles that become "alive", one that react, adapt, mutate, transform and repair themself. These textiles which embed digital technologies will provide new sensorial qualities that will anable novel ways of how we will experience and interact with our surrounding. This means that time has come for traditional textiles designers to change their understanding of the media with which they are working on their daily basis and realize the potentials that computation and responsive materials offer.

This thesis is focused on traditional textile designers who are troubled by the fact that a lot of the responsive materials and digital technology that they encounter are more technical than aesthetic. The goal is to bring computation, electronics and responsive materials closer to them and present those as a design material.

7 Defining the problem

Based on the research presented in the previous chapters, the goal of this thesis will be:

"To examine the intersection of computation with traditional textiles, and understand how their integration is perceived as means for creative expression."

The subjects in focus of this thesis are textile designers. To examine the stated problem, the project *Interactive Book Samples* will be used as a framework.

PART 2: DESIGN AND IMPLEMENTATION

8 Design

The following chapter presents the design process related the development of the Interactive Sample Book. It will start by describing the specifications about each of the samples, the material requirements, the initial design and functionality, as well as the challenges. The work involved a very hands-on approach, as many experiments were made to find the right materials and techniques that will later be used for the implementation. During this process I will try to look at electronics not only from a functional point of view, but also as design elements. For that reason, the design and technical specifications for the samples are not separately defined, as I look at electronic pieces as potential source of inspiration.

8.1 Interactive Book Sample

As already mentioned, the Interactive Book Sample consists of five textiles which are responsive to the input of the user. Thus each textile demonstrates a particular aesthetic and interactive functionality. The five samples are different from each other, presenting diverse examples of how responsive materials combined with sensor technology and computing can create new and dynamic ways of textile expression. The sample book has been designed with the idea that each sample should tell a story and with that focus on stimulating specific senses. The goal is also to make each sample stimulating, aesthetic and surprising.

An initial idea of how the book should look can be seen in Appendix B. The size of the samples will be approximately 50 x 50 cm. The instructions to each sample will be very limited, in order to let the user explore the book on one’s own. Together with the sample book a booklet will be provided, containing more information about the technologies implemented in the development of the samples. The booklet will also include examples of similar existing projects and possibly information to suppliers.

The concepts and material choices for the five samples were developed based on the role responsive materials could have as sensors and actuators. The following materials were chosen as sensors: photovoltaic cells, pressure sensors, sound sensors, strain sensors; and as actuators: shape memory alloys, light emitting diodes, electroluminescent materials, photovoltaic cells, optical fibers, thermo chromatic and photo chromatic inks. It should be mentioned that some materials are both sensors and actuators, such as photovoltaic cells, thermo and photochromic inks.

In the very early stage of the project a decision was brought to focus on the development of only two of the materials. This decision was based on the approximated amount of work for each of the samples and the previous experience with responsive materials. Thus the design and the experimental work presented in the following sections is focused mostly on the first two samples (*Sample 1*, *Sample 2*). A short description of the last three samples (*Sample 3*, *Sample 4* and *Sample 5*) is also provided in order for the reader to have a better understanding of how the Interactive Sample Book was envisioned, as well to show the diverse number of responsive materials and technology that can be used.

8.1.1 Brainstorming of ideas

The basic concepts for all the samples were developed by Priya Mani, Elisabeth Heimdal and I (Marija Andonovska). These concepts were then further developed with contributions from the whole team. The aesthetic direction of each sample was derived as a result of a brainstorming session. Similar projects were reviewed for each sample, and positive and negative characteristics were given. Those were further discussed in relation to the sample book and narrowed down to several words that best describe the design, aesthetic and emotional expressions we wish each sample to generate. The process is illustrated in Figure 14.

Figure 14 - Inspiration walls – Pictures related to Concept B (left), Concept A (middle) and Concept C (right)

8.1.2 Design specifications

This section describes the five samples, the design, the technical and the material choices, as well as the challenges, the experiments and the reasoning for the related decisions.

Sample 1
Story: The textile that can change shape
Senses: Vision and touch
Input: Touch – soft switches
Output: Movement – shape change of the fabric
Materials: shape memory alloys (SMA), conductive fabric, power supply, microcontroller, conductive thread and base fabric.

The intention was to design a responsive textile which changes shape when the user touches certain areas of the textile. Depending on which area is activated, different shape changes will occur in defined areas of the sample. The textile should be perceived as dynamic, organic and three-dimensional, as if it becomes alive. The idea was to avoid mechanical and sudden movements. They needed to be natural, subtle and animated in a predefined way. Inspiration regarding the shapes the textile could make was found from the floral and aquatic world. Figure 15 illustrates some of the initial ideas about this concept and the inspirational work from design studio XS Labs. One of their most inspiring projects implementing SMA is *Kukkia and Vilkas* by Berzowska and Coelho (2005). The project visualizes some of the potentials with SMA, which aesthetically encourages a sense of wonder and delight. These are also the expressions we would like the user to experience when interacting with the material.

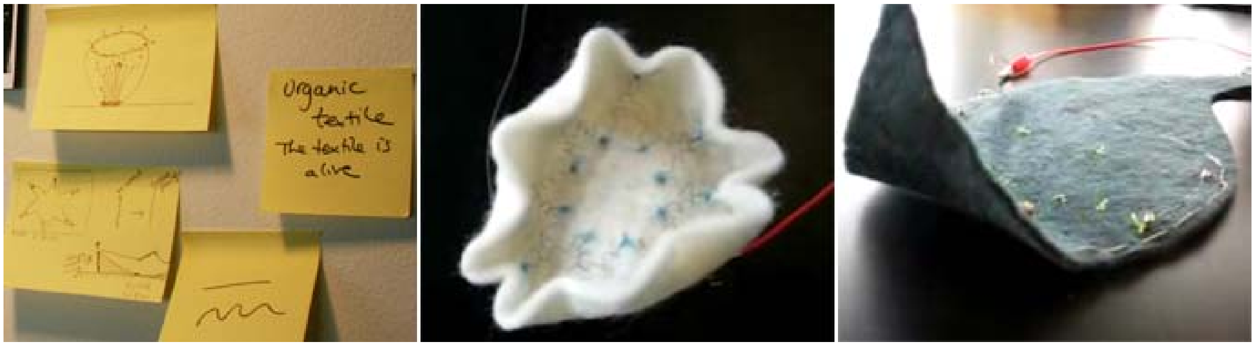

Figure 15 - Initial drawings (left picture); Experiments from XS Labs[25] used as inspiration (middle and right picture)

Functionality

The user will be able to interact with the sample, by pressing certain areas of it. Those will be in the form of soft switches that send signals to the microcontroller, which then triggers an output noted by the user as a change in the surface of the textile.

Challenges

The biggest challenge for this sample is to predict the behavior of shape memory alloys, which will create the movement of the textile. The sample will have to change shape over time, with resistive heating and controlled electronics.

Experiments with Shape Memory Alloys

In order to find the shapes and movements for the final version of the sample, numerous experiments were conducted with different shapes and diameters of SMA. Also experiments with different lengths were made. This was a very long and complex process. There are very few documented projects we could refer to. As already explained in chapter 3.6, SMAs have an ability to recover any shape pre-programmed, upon heating until reaching their transformation temperature. The several attempts to test the SMAs by running electricity though with common AAA batteries were unsuccessful (see Figure 16). The problem was that the SMAs were not pre-programmed (formed in a specific shape and heated at

[25] http://www.xslabs.net

very high temperature). The thick Nitinol tubes we experimented with were difficult to change, without being shape-set at very high temperature. Another challenge was to find the right voltage and the right length where significant change can be noted.

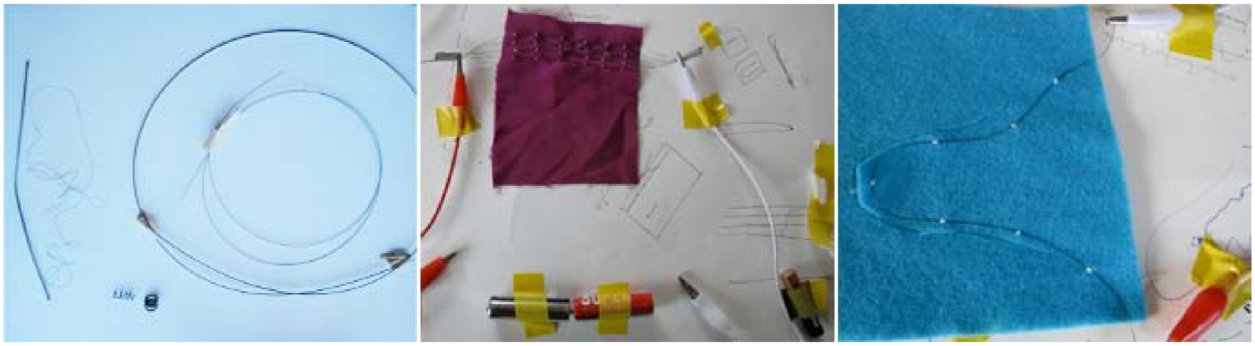

Figure 16 - Samples of SMAs (left); Experiments with different forms of cloths (middle and right)

For that reason, experiments were made in a lab in the Mechanical Engineering Department in the Technical University of Denmark (DTU), where with a help of a rectifier[26] we were able to adjust the amperage and voltage, to a point which is making the SMAs change shape. However also this was not sufficient. The first significant progress was archived after a number of SMAs were pre–programmed first at 700 degrees, then at 500 degrees, after trial and error. The process toke approximately 10 minutes and the SMAs were shaped in zigzag and spiral form. They were further used for testing with different materials, to find out which combination would give the most dramatic and aesthetic effect.

Figure 17 - Rectifier (left); Shaping SMAs (middle); Furnace (right)

[26] An electrical device that allows one-way flow of electrons, from alternating current (AC) to direct current (DC). - http://www.allaboutcircuits.com/vol_3/chpt_3/4.html - 24.05.2009

In Figure 17 the picture to the left illustrates one of the experiments with the rectifier; the picture in the middle presents a shape-set of a SMA and the picture to the right is the furnace used to pre-program the SMAs at very high temperature.

Experiments with soft switches

Soft switches can be made easily by placing two layers of conductive material in such a way that they are slightly separated from each other by another thicker fabric. The center portion of the ticker fabric has to be cut of, or a piece of netted fabric, such as tulle, can be placed in the middle of the two conductive layers. When pressure is applied to the top of the conductive layer, the circuit is closed, allowing electricity flow. Figure 18illustrates experiments with different conductive fabrics and shapes of soft switches as testing the sensitivity which can be adjusted by changing the thickness of the middle fabric. This way one can control the amount of weight or pressure it is necessary to close the circuit. The advantage of soft switches over traditional ones is that they can be designed in different forms as they are able to easily conform to almost any 3D surface.

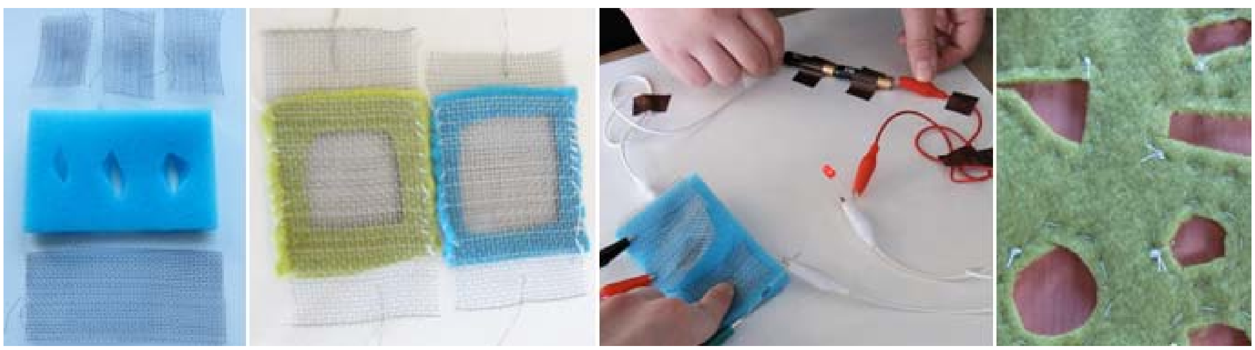

Figure 18 - Testing different sensitivity (most left); Soft switches are connected with conductive thread on both side and can be used in a circuit; When pressed, an LED is on; Different shapes of switches (most right)

Experiments power supply

To avoid using power supply which is usually bulky we have considered an alternative such as using coin size batteries placed in little pockets. The top side of the coin pocket has a metal button attached to it, which is also touching the positive side of the battery. A connection with the circuit can be made by attaching conductive thread to the metal button. The bottom side is closed with conductive tape, which is touching the negative side of the battery. The conductive tape can also be connected to the electrical circuit by a connection with a conductive thread. The coin pocket can be easily snapped on and off the fabric through the metal button, which has its opposite part attached permanently on the fabric. This is one of the ways for reducing the number of hard electronics to be placed on a fabric. If necessary more of these small batteries can be seamlessly integrated in the sample. This concludes the design process related to Sample 1 - the textile that can change shape.

Sample 2
Story: The textile that has eyes and blinks back at you
Senses: Vision
Input: Light
Output: Light
Materials: LEDs, photovoltaic cells, optic fibers, UV(ultraviolet) torch, microcontroller, conductive thread, three types of fabric and power supply, conductive tape and conductive epoxy

The focus area for this material is on the human sense, vision. Light is both the input and the output, it is dynamic and transformed from one to another energy source. The user interacts with the textile through a UV torch, powering the solar cells, where the textile responds with different light patterns depending which solar cell is illuminate. The expected effect is that the user perceives the textile as something one can communicate with. There is a feeling of correspondence, an immediate response between the input one makes and the generated output. Each solar cell should create several light patters, so that the response becomes unpredictable. The textile designer Priya Mani envisioned the textile as the night sky, thus the choice of materials and further creation will be based on this concept. The lights are spread through the material creating patterns like the start constellations, appearing one by one on the textile, with different brightness, creating the illusion of depth.

Figure 19 - The night sky as inspiration (left); optical fiber (middle); LEDs powered at night from energy collected by solar cell during day time

Functionality

The light from the UV torch is transformed into power by the solar cells, which send signal to the microcontroller, which outputs power to selected LEDs, creating a dynamic light pattern as a response to the UV light from the torch.

Challenges

Challenges lie in the integration of solar cells onto the textile and the creation of connections between the solar cells and the light sources. The solar cells should be flexible, to retain the flexibility and the lightness of the material. Another challenge is the integration of the optic fibers in the textiles and their placement on the material.

Experiments with solar cells

To preserve the natural softness and flexibility of the textile, flexible solar cells were considered for the design. Risø National Laboratory[27] was contacted, as one of their research areas in sustainable energy supply is focused on the development of plastic solar cells. The advantage of these polymer solar cells, compared to the silicon ones which are currently available on the market, is that they can be produced at a very low price; they are extremely flexible and can be printed in any desired shape. However, even if

[27] http://www.risoe.dk/Research/sustainable_energy/Solar_energy.aspx - 27.03.2009

they are promising candidates of future ultra low cost solar cells; their efficiency in the moment is very low. After some experiments, we concluded that another type of solar cells is necessary.

Another type of paper thin, flexible and efficient solar cells was found. According to the producer[28] the solar cells are made by depositing silicon on a thin plastic substrate and then the cell is encapsulated with polyester coating. To test the solar cells alligator clips were attached to the copper tape strips located at each end of the solar module. The coating over the copper tape was scraped away to ensure direct contact. The solar cells were very efficient and tested with various types of LEDs.

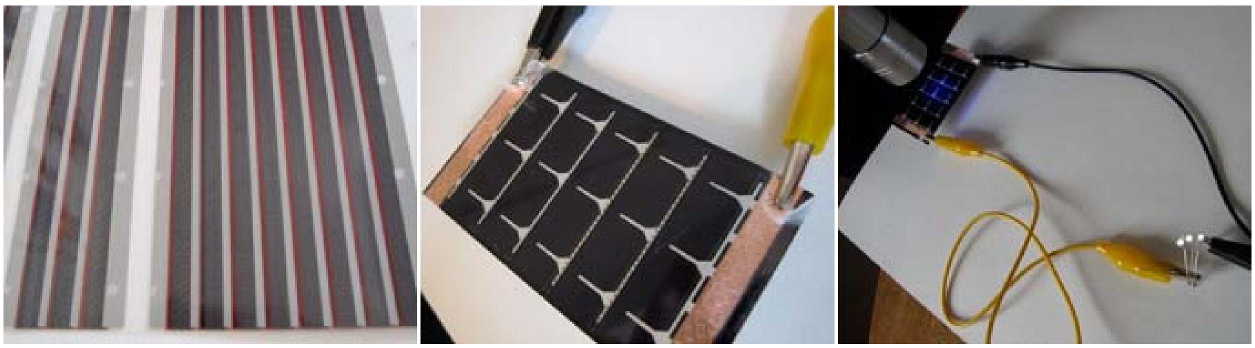

Figure 20 - Solar cell from Risø (left); Soral cell used for the sample (middle); Solar cell powering 3 LEDs (right)

Experiments with optical fibers

Several experiments were also made with optical fibers, both side- emitting and end- emitting. Even thought the side-emitting were very interesting possibility, they proved not to be efficient. Optical fibers are flexible; however they are very difficult to work with when attaching them to a fabric. Figure 21 llustrates some of the techniques tried to see which approach will better fit the design of this sample. For the final sample, end–emitting plastic fibers were chosen. When placed on top of an LED, light is transported to the end of the fibers.

[28] http://www.flexsolarcells.com – 29.03.2009

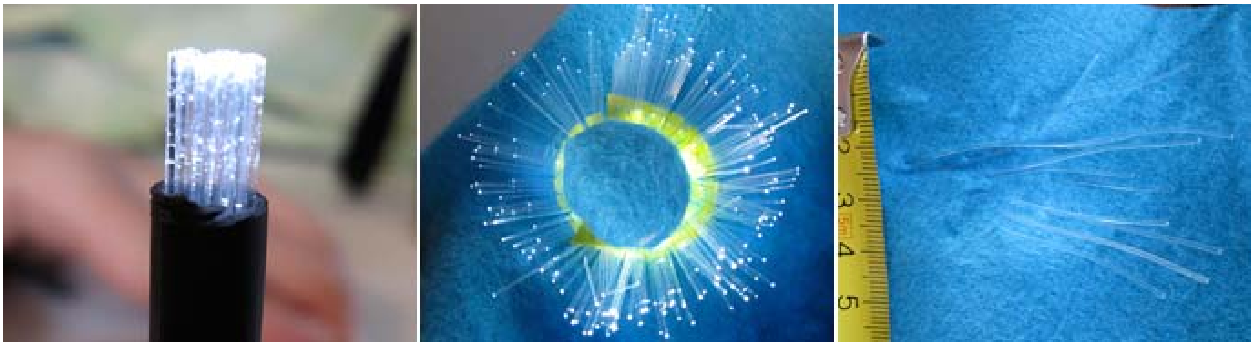

Figure 21 - Different ways of embedding optical fibers in a fabric

Experiments with LEDs

A variety of LEDs were considered and tested in combination with the optical fibers, solar cells and different types of fabrics. Their brightness and their size were of importance. The LEDs required should be very small in size, but also very powerful. Figure 22 (the two first pictures from the right) present the LEDs chosen for the implementation in the final sample.

Experiments with conductive thread

While not as conductive as traces on a printed circuit board (PSB) or wires, they were still able to carry current for power and signals. Conductive threads with low resistance are better conductors. Tests were made with a conductive thread received from a research lab[29], with very low resistance of 6 Ohms on 30 cm however it was difficult to work with it, as the thread was easily fraying. For the final version of the sample we decided on using a commercially available conductive thread with 82 Ohms per 30cm, with a thickness of 117/ 17 2ply (Figure 22 – most right).

[29] http://www.titv-greiz.de/ - 22.04.2009

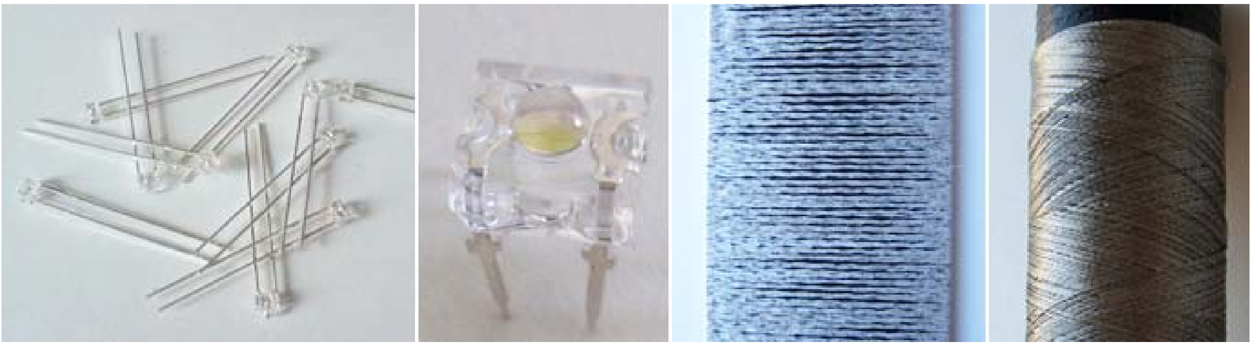

Figure 22 - Superbright 1,8mm white LEDs (most left); Piranha LED; Conductive thread with 6 Ohms; Conductive thread with 82 Ohms (most right)

Regarding the design of the surface of the textiles, a lot of considerations were made about the type of fabrics and their integration with the electronics. The number of LEDs, solar cells and fiber optics were combined to find their aesthetic placement on the textile. The aesthetic design of the sample together with technical design is very much interrelated.

Design of the circuit

The design of the circuit is presented in Appendix C. Before this version, many others were made. One of the first designs included the microprocessor placed in the middle with all the connections going out to the LEDs and solar cells. This design was reconsidered several times to avoid crossing of conductive threads. Thus the final technical design was made by placing the microcontroller on the bottom left side providing easy access to it for switching on and off and for uploading new code.

The yellow marks on the picture represent the LEDs which should be directly powered from the solar cell. Each solar cell is connected to the analog inputs of microcontroller. Thus the solar cell becomes both a sensor and an actuator. By connecting some of the LEDs to the microcontroller and some to the solar cells, we wanted to create diverse levels of the brightness from the LEDs. Another form of light dispersion is created with the optical fibers which should be lit by LEDs from one end and light can be seen from the other.

Special plans were also been made for the placement of the LEDs which will be connected to the microcontroller, the LEDs connected directly to the solar cells and the optical fibers. Patterns were quickly simulated for the active LEDs for each solar cell when light is pointed at it. Each solar cell has three patterns, with the intention to make the experience less predictable for the user, but still not totally random. After interacting with the pattern for few minutes the user should be able to see patterns repeating. Two small physical prototypes were created with one and later four solar cells and several LEDs to consider the different light effects one can expect. This was very important for predicting the outcomes of the light effect, as well choosing a technique which would be used in the implementation stage. With this the material considerations for the *Sample 2 – the textile that blinks back at you*, have been finalized.

Sample 3

Story: The textile you can talk to

Senses: Audio and vision

Input: Voice, sounds

Output: Light

Materials: Sound sensors (microphone or piezoelectric material), electroluminescent (EL) wires, inverter, microcontroller, power source and conductive thread

As the user speaks, sings or creates other sounds, the light patterns illuminate. They become visible from under the fabric. Different sound frequencies correspond to specific patterns. The light is generated from electroluminescent wires, which are embroidered into the fabric. The intention with this sample is to create a textile that is dynamic and sensitive to audio stimuli. The user should see the textile as a playful and fun experience.

Functionality

A sound sensor is connected to a microcontroller, which decides which light pattern to activate, depending on the sound frequency. The light patterns are made of electroluminescent wires embroidered onto the textile or integrated in other ways into the textile. One could imagine that there are three frequency intervals with each its own corresponding light pattern.

Challenges

One of the challenges in this sample is creating the correspondence between the sound frequencies with the light patterns. To avoid "flashy" effects from the wires, the possibility of adding dimming effect is considered. Creating the light intensities as well as connecting several EL wires through the inverter[30] and with the microcontroller is another challenge.

Experiments with the EL wires

In order to have sound activated EL wires we first looked at inverters trying to find the smallest in physical size. Furthermore we were investigating whether one inverter can power a single EL wire or several in parallel. Each EL wire would have to be connected to a microcontroller using three digital output pins. In the circuit between the EL wires and the microcontroller a chip (CD4066) could be used to control the on and off functions. Adding the chip to the circuit, with four switches packed inside, can control three inverters, thus controlling three EL wires. However, adding three inverters is not a good solution, so another approach needs to be considered.

Figure 23 - Inspiration picture (left); EL wire connected to an inverter (middle); Soldering of EL wire with a connecting wire from the inverter (right)

Considerations about sound sensors

For a sound sensor both piezo and capacitor microphones were considered. They are very small point-size devices which can easily be attached to a fabric. If piezo microphone is used, which basically works on mechanical stress (pressure) from the sound waves, a very simplified reaction to sound can be

[30] An electrical device that converts direct current (DC) to alternating current (AC)

achieved by threshold detection - which means we check if the input amplitude is above a certain level, and if it is, an output is sent, in this case, a digital output on the microcontroller will turn on an inverter with an EL wire. This however will not discriminate between different sounds, so it would be activated by footsteps and voice alike, as long it is loud enough. The implementation of piezo microphone is doable, but very limiting. Thus we consider another type of microphones. Capacitor microphone capsule has an approximate diameter of 1.5 cm, requiring power of possibly 5V, a resistor and a capacitor in order to get the voltage out of it. Such microphone capsules can also be easily embedded in the textile, almost seamlessly; however problems arise when capturing the sound with a microcontroller, which requires: sampling a channel, perform audio processing and perform output (activating the EL wires). Some to mention are problems with power supply, processing speed and capacity for filtering sounds and storing values. These were a few of the considerations regarding the combination of EL wires with the microprocessor and a microphone, as an input. There were many other uncertainties around the combination of all these elements, so a decision was made not to focus on this sample more. Further development might bring a more ‘elegant’ and compact solution, which will not constrict the flexibility of the textile.

Sample 4

Story: The textile that can remember

Senses: Touch and vision

Input: Mechanical strain

Output: Heat, light and color change

Materials: thermochromatic ink, photochromatic ink, electroluminescent (EL) wires, conductive threads, resistors, power supply, inverter, microcontroller

Visual traces are created on the textile as a result of the user interacting with the elastic strings. There is correlation between how hard the strings are pulled with much color appears on the fabric. After the user stops pulling, there are still visible traces. One gets the impression that the textile can remember and continues changing long after an action has been performed. Sensors measure how much the elastics are stretched and heating or lighting threads are activated as a response to this. Thus the thermo- and photo chromatic inks are activated and respond in change of color. The thermo-chromatic ink responds to the heat generated from the conductive thread, while the electroluminescent wires activate the photo chromatic ink.

Functionality

The strain sensor sends signals to the microcontroller, to send output corresponding to the value from of the sensor, on how much light or heat should generated in different areas of the sample. This light or heat then changes the color of the fabric in a given area, using photochromic or thermochromic inks.

Challenges

One of the challenges with this sample is to find or develop a suited strain 'soft' sensor.

Sample 5

Story: The textile that notices your presence

Senses: Vision and hearing

Input: Hand movement (without touching the textile)

Output: Sound and light

Materials: Photocells, optical fibres, mini speakers, microcontroller, power supply

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It is a textile that responds to the presence of the human hand over it. Moving the hand above the textile creates a reaction in a form of sound and light. Depending on which part of the textile the hand is moving above, different parts of the textile are enlightened, and small speakers emit sounds.

Functionality

Photo resistors are placed on the top of the fabric. They work in such a way that their resistance varies in response to light levels, typically decreasing resistance as light levels increase. Thus when the users hand is covering the photo resistor, creating a shadow, a signal is send to the microcontroller to trigger the emission of light and sound on the given location.

Challenges

One of the challenges with this sample is connecting the different sensors to the actuators (the optical fibers and the miniature speakers).

8.2 Sub- conclusion

From the above description one can see that all of the samples have been considered as self-contained pieces of fabric. The design and technical considerations are striving towards development of responsive samples utilizing soft computing as a way to preserve the natural qualities of the chosen textiles. However problems arise when considering the implementation of the power supply to the fabric. Current available and efficient sources of supply are batteries and adapter, which usually are big and heavy. Flexible solar cells can be employed in some cases however they are still not efficient for all purposes.

Furthermore, many of electronic elements and devices which have been considered and experimented with during the design stage are not initially produced to be embedded in a textile. Thus many of the problems related to this stage were how to seamlessly integrate them in the fabric. This meant using unconventional ways of attaching and connecting electronics to the fabric or as part of the circuit.

Having chosen all the materials and designed not only the aesthetic but also the technical aspects of the first two samples the next step is their implementation.

9 Implementation

The focus during the implementation stage was to simultaneously consider aesthesis, functionality and as well as retaining the natural characteristics of the textiles, within the design frame and chosen materials presented in the previous section. This chapter will first look into the choice of microcontroller as a physical computing platform. After this follows a section that details the realization of the design specifications with regards to *Sample 1* and *Sample 2*.

9.1 Choice of physical computing platform

This section will give an overview of the chosen physical computing platform as it is intended to be used for the implementation of the both samples. The section ends with reason why this specific platform was chosen.

LilyPad Arduino is a physical e- textile computing platform build on a simple I/O. It is a wearable technology developed by Leah Buechley (Buechley & Eisenberg, 2007) and SparkFun Electronics (SparkFun Electronics - LilyPad Arduino 328 Main Board, 2007). The main board consists of an ATmega328 microcontroller with a pre-programmed bootloader that simplifies on uploading programs on the chip and a minimum number of external components to keep it as small as possible (50 mm in diameter, 0.8mm thick and 3 mm where electronics are attached). It was designed with twenty large pads to allow to be sawed onto textiles, with a conductive thread, connecting various inputs, outputs, power and sensors devices. The main board runs at operating voltage of 2.7 -5.5V and 40mA. It can be power with a USB or with an external power supply. Both the main board and the external power supply are flat on the flat on the back, so they can easily be placed on the surface of the fabric. The only negative aspect about the power supply is the battery holder which is still bulky and not so practical, but it is definitely an improved version of the traditional power supplies for electronics.

Figure 24 - LilyPad Arduino Main Board (left); Power Supply (middle); LilyPad E-Textile Kit (right)

From the twenty pins on main board, fourteen are digital I/O Pins and six analog I/O Pins. The digital pins on the LilyPad Arduino can be used as either inputs or outputs. By default they are set as inputs, but if output is needed, then they have to be explicitly declared as such. Six of the digital pins have integrated pulse width modulation (PWM)[31] technique, pin number: 3, 5, 6, 9, 10 and 11. The output pins are analog–to-digital (A/D) converters and mostly used to read analog sensors. But if more general purpose input output pins (GPIO) are needed, and all the analog pins are not in use, the analog pins may be used for GPIO. The pin numbers corresponding to the analog pins are from 14 to 19.

The LilyPad Arduino developing environment is using the name *sketch* for a program. It is the code, written in the programming language C, which is uploaded to and run on the main board. The LilyPad Arduino sketches can be stand-alone or they can communicate with software on a running computer such as Flash, MaxMSP and Processing. An interesting fact about the LilyPad Kit (consisting of main board, power supply and various sensors) is that it is washable. For the purposes of this project we are only using the LilyPad Arduino Main Board and the LilyPad Power Supply.

The reason for choosing this LilyPad Arduino over other kinds of physical computing platforms is that it is specially designed for e-textiles, which means the mounting of the electronic elements on the main board have been made with a consideration that they will be used on a textile, and this is also implemented in the relation with the dimensions and the weight of the elements. Furthermore, it allows the transfer of data and power between electronic elements to be made with a conductive thread, which makes circuits soft, flexible and lightweight.

[31] According to the official Arduino website (Hirzel, 2005) PWM is: a technique for getting analog results with digital means. Digital control is used to create a square wave, a signal switched between on and off. This on-off pattern can simulate voltages in between full on (5 Volts) and off (0 Volts) by changing the portion of the time the signal spends on versus the time that the signal spends off. The duration of "on time" is called the pulse width.

9.2 Implementation of the Interactive Samples

Sample 1: The textile that can change shape

Based on the design phase, the following materials have been chosen for the final version of the sample.

Fabrics: the sample is made of two fabrics placed on top of each other. The base fabric is felt and the top is thin fabric cut in circular motion lines. The pattern was designed by Hanna–Louise Johannesen (Diffus).

Flexinol: This is a trade name for Nitinol (SMA). We decided to use 0,5 mm in diameter. The Flexinol was constrained in the desired shape and it was heat-treated at 500 degrees. The zigzag shape of the wire provided the greatest amount of change on the fabric (Figure 12, middle picture). There are currently three Flexinol wires attached to the top fabric.

Soft switches: From the different types of conductive fabrics, electronylon is the one chosen for making the soft switches. Electronylon has the highest conductivity from the other considered materials. It has exceptional electrical conductivity of 0 Ohms per 100mm measured on a 25mm wide strip. The copper coating on the surface, it gives an overall copper appearance but this can change quickly if it is handled frequently. Soft switches will be integrated under the top fabric, thus act as touch sensors (Figure 26, left picture).

Microcontroller: The microcontroller is active when a soft switch is pressed. This triggers the microcontroller to send signals in a form of PWM (pulse width modulation), which, as explained in the previous section, is chopping the signal into a square wave of a variable pulse width. The reason for programming the microcontroller to send PWM is to control the movements of the shape memory wires in a desired manner. When the PWM signal is send power is supplied to shape memory alloys which makes contraction. An overview of the circuit and the connections between the electronic elements is included in Appendix D.

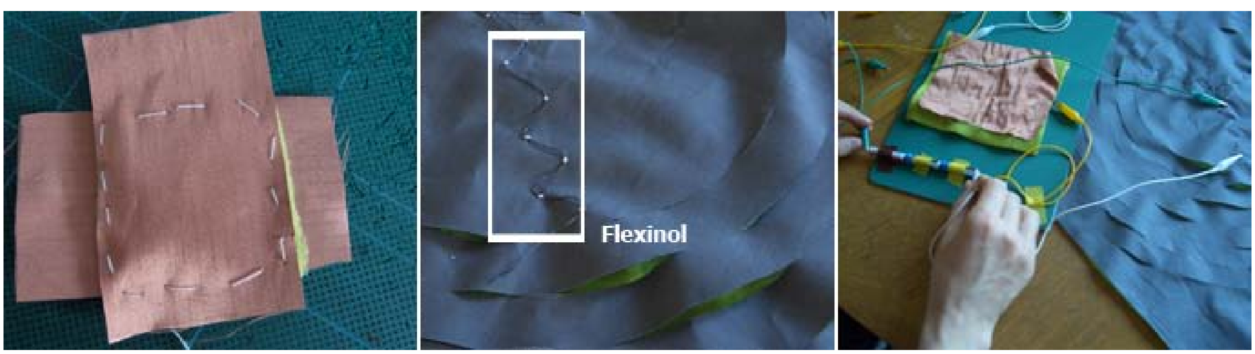

Figure 25 - Soft switch made from electronylon (left); Flexinol wire in a zigzag shape (middle); Heating the Flexinol wire with 2 AAA batteries (right)

This sample is not fully completed due to lack of time. What is missing is the programming of the microcontroller to power the change of the SMA wires. However, a demonstration of change on the surface of textile can be provided with a simple circuit powered by two AAA batteries (Figure 11, right picture). The effect to the textile when heat is applied to the Flexinol wires is presented through three pictures in Figure 27.

Figure 26 - Change in the surface of the fabric, the pictures are taken with an interval of few seconds

The effect is wavy and organic movements[32]. They can be modified by programming to more dramatic or subtle motions.

Sample 2: The textile that has eyes and blinks back at you

This sample has fully been implemented based on the design and technical specifications. The following materials have been used in the final version of the sample.

Fabrics: The sample is constructed of three layers of different fabric. The base fabric is felt on which all the electronics and circuitry is placed. The middle fabric is used as a way to hide the microcontroller and the power source. This fabric has little wholes through which only the LEDs come out. It is also used to hold the optical fibers which are vertically placed on top of four LEDs. The top fabric is see-through, with a role to reduce the bright light from the LEDs, however interesting light effects are created on the fabric, since it is placed as a wave.

[32] Video of the demonstration is included on the DVD in the Video Folder under the name Sample 1.avi.

LEDs: There are two types of LEDs implemented on the textile. Twenty-five superbright 1,8mm white LEDs, which require between 3.0 – 3.5V and 25mA. Fifteen of these are connected to five solar cells (three to each solar cell). There are also four Piranha High-Flux LEDs that require 3.1 -3.4V and 20-30mA. These four LEDs are used under the end-emitting optical fibers. The leads of the LEDs were placed horizontally or bend in a loop, so that they can easily be positioned on the surface of the fabric (Figure 28, right picture).

Solar cells: The chosen solar cells are flexible with the following dimensions: 0.2mm thickness and 0.7g weight. This makes them suitable for easy implementation on the fabric; as well they do not add additional weight to the sample. For the solar cells to be functional they are powered with a UV light, which the user has a control over. The output can vary depending on how far the light source is allocated from the cell. The output is between 3.0 - 4.1V and 22mA – 30mA. The solar cells are polarized, which means one end is positive and the other negative. Since they are very thin, instead of solder (soldering iron can melt through the clear coating over the copper tape), we used conductive epoxy and conductive tape to attach wires for creating easier contact with the conductive thread (Figure 28, left and middle picture).

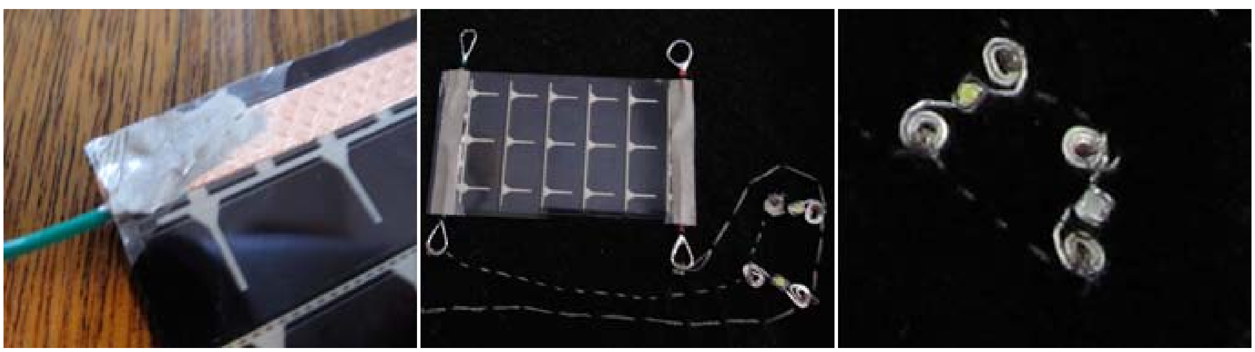

Figure 27 - Applying conductive epoxy over the copper tape (left); specially made hook for attaching the conductive thread (middle); LED leads bend in a loop (right)

Microcontroller: All the solar cells are attached to the analog inputs from the microcontroller. When the user points the UV torch to a solar cell a signal is sent to an analog input and the corresponding code is executed. A full copy of the code with comments is included in Appendix E. As already mentioned in the design process each solar cell has three patterns, each one an array of numbers of output pins which should send a signal out when the code is executed. This gives a total of fifteen light patterns. The digital pins of the microcontroller are used as outputs to the LEDs. Some of the LEDs are fading in and out, while others light on and off without a fading effect. This is because only some of the digital pins have the integrated function PWM. All the connections between the solar cells, the LEDs and the microprocessor are made with conductive thread. Because of the resistance in the thread, the LEDs which are further away from the microcontroller shine a bit less bright, then those closer to it. The best effect can be experienced by testing the textile in a dark room[33].

Figure 29 (from the left) presents the LilyPad Arduino and the power supply connected together, with many connections coming out from almost all the pins on the board. The middle picture shows the working circuit and the last picture shows the top fabric, which covers everything except for the solar cells.

The textile is light and flexible, as well as self-contained. The only requirement is that the UV torch has to be fully powered to give a good signal to the solar cells, which then trigger the execution of the code.

Figure 28 - LilyPad Arduino with power source (left); Overview of the circuit (middle); Finished sample (right)

9.2.1 Sub-conclusion

The above sections have fully described the development and functionalities of the textiles. Only two samples have been implemented from the five concepts described in chapter 8. The first sample is partially developed, where the second is fully functionally according to the design specifications. Even though the first sample is not completed it is still possible to demonstrate the intended functionality, using a simple circuit. Having the two samples ready the next step is surveying on a sample[34], which will allow for better understanding of how integrating technology with textiles is perceived as means for creative integration by other textile designers.

[33] Video demonstration is included on the DVD in the Video Folder under the name Sample 2.avi.

[34] Subset of a population (in the case of this project: textile designers).

PART 3: METHODOLOGY, SURVEY AND FEEDBACK

10 Methodology

Introduction and discussion of the survey carried out will be brought forward in this chapter, together with considerations for the selected survey methodology. A presentation of the feedback will be followed up by a discussion and evaluation on the success rate of the survey. The conclusion will be presented at the end of this chapter.

10.1 Survey methodology

Based on the finial problem formulation ***"To examine the intersection of computation with traditional textiles, and understand how their integration is perceived as means for creative expression."*** Heimdal and I conducted a one-hour classroom survey with the participation of nine subjects (eight textile design students and one textile design teacher from Danish Design School) in order to better understand how integrating technology with traditional textiles is perceived as means for creative expression. As an additional part in this survey we also examined the perceived level of creative integration of technology versus transparency. For this survey purpose, the following hypotheses were developed:

1. The e-textile sample is perceived by the subjects as a traditional textile with properties such as: soft, flexible and self-contained.
2. The subjects are inattentive of the existence of the electronic devices, which have been embedded in the textiles.
3. The subjects perceive the electronic devices and responsive materials as new materials in the design process.

To examine, although not attempting to verify, the validity of the hypotheses a qualitative approach in the form of a survey was used. The survey was planned as a workshop, with the aim to create a familiar, relaxed and casual environment in which the participant would feel comfortable and safe enough to express their genuine views on the topic.

The workshop was conducted in one of the classrooms in Danish Design School where it was documented on video footage. The classroom, in which the workshop was held, was adapted for this purpose. The developed samples were placed visibly in the centre of the classroom on one of the tables, together with other related materials such as elements used for the development of the samples. On the wall we placed posters with pictures and short explanations of the materials used for making the samples. Also pictures from similar e-textile projects were placed on the wall. The reason for this was to make the participants more familiar with the topic. Paper and pencils were provided so the participants could better conceptualize their ideas and write comments during the second part of the classroom survey.

As part of the workshop, Product Reaction Cards[35] were given with the intention to get as many word descriptions about the samples as possible. From previous experience (Andonovska, Cerda, & Ravn, 2008) with qualitative interviews it seems that participants often find it difficult to give descriptions containing a broad range of adjectives about the objects they are asked to describe, however it is easier to get responses from the participants had they have been presented to pre-written words, which they can choose from.

The Product Reaction Cards (see Appendix F) were adapted to match the object presented: *Sample 2 (textile that has eyes and blinks back at you)*. From 118 words originally designed for the Product Reaction Cards, were chosen. The participants were asked to choose as many words as needed for describing the sample. In conjunction with that, they were then asked to pick only the five most relevant words from the list of words, which they had already chosen. The survey, having been planned as a workshop, did not allow for individual interviews.

10.1.1 Survey background and procedure

The survey, in the form of a workshop, took place on the 20th of May 2009, was lead by Heimdal and I (Andonovska), and had a total of 9 participants: Eight students and one teacher. The eight textile design students were between the ages of 20-30 years. They were all second and third year students at the Danish Design School's bachelor program. The teacher was as well from the Danish Design School. As part of their education it turned out that the students only possessed elementary knowledge on e-textiles and functional wearables. Also they had a very basic level of practice related to this topic. Furthermore, as it turned out, due to the limited theoretical knowledge, this resulted in most focus having been placed on the aesthetical aspects and almost none on the enabling features of wearable technology. Below is a clarification on the workshop's four main parts:

[35] Developed by Microsoft Corporation (2002). All rights reserved.

Part one (approx. duration 20 minutes)

The workshop started with a presentation of the two samples. This was done in a twofold way: First as a story and then as the technology behind the story. The students were given the opportunity of interacting with the samples individually. During this session they asked questions and commented on what they saw and experienced regarding the samples. After this a more detailed explanation of the technology and materials used in the process of making the samples was given.

Part two (approx. duration 20 minutes)

During this part of the workshop the students were divided into groups of two, each given a context for which they were asked to develop ideas, based on the previously presented materials. Working in groups was considered to be a good approach, as the participants were all used to work in groups on projects as part of their education. More importantly as this workshop was based on a completely new area, being e-textiles, it was assumed that the participants would feel more confident during the design process given the fact, that they were able to discuss ideas with their fellow students and teacher, in the accustomed environment of the school's workroom culture. The areas for which they were asked to develop ideas were:

- Outdoors
- The office
- The living room
- A children's room in a hospital

The areas were chosen with a consideration for the fact that the design students should be familiar with designing for similar spaces. They were asked to represent their ideas using sketches and followed up with explanations on how these should be materialized, including the materials they would use for this purpose.

Part three (approx. duration 10 minutes)

In order for the focus group to choose the words, which they thought describe *Sample 2* most precisely, Product Reaction Cards were handed out. From these cards, they were asked to select as many words as they found necessary to describe their present emotions.

Part four (approx. duration 15 minutes)

As seen in the video footage documenting the full survey, each of the four groups was given the chance of presenting their ideas. This brought forward a group discussion about what the group participants found exciting about the samples and how they got their ideas. They were also asked to explain what they thought about the technology being integrated with the textiles. With this the workshop was finished.

10.2 Survey Feedback

The feedback from the survey is presented in four parts based on the way the survey was carried out. After this a summary of the feedback will be presented. All the quotes in this section are taken from the transcript (Appendix G) of the video, made during the survey.

Part one

This is the part of the survey in which the samples were presented and the participant had the opportunity to interact with textiles, ask question and give their comments.

First Sample 2 was presented. The participants were interested in understanding how specific parts of the sample work, for example how the connections are made between the elements attached on the textile, or what they are made of. The following quotes illustrate this very well:

Teacher: *So what you said, is that the little computer is programmed so that if you have been in this one before you come here, it will do differently than if you were here before?*

Student: *And then this threat makes this connection?*

Heimdal: *Yeah, this makes the connection. And then this is also another kind of threat, which can be used to make the connections.*

Teacher: *What is it made of?*

Heimdal: *It's made of a blend of nylon and silver…*

Student: *And these solar cells, are also really… they are not textile of course, but they are totally bendable… "*

Right after they were able to try the samples the teacher started questioning the significance of the computing devices and responsive materials*, ”…What's the idea?...”* she asks*.* It is her opinion that the contrast between the computational devices and responsive materials, and textiles it is still too big, the elements used in the sample are not textiles. She questions why they should be on a textile.

An interesting part of this section that needs to be mentioned as well is that both the teacher and students wanted to know the context in which this sample should be used. Heimdal explained that the samples are without a function or application as such, but by showing what a number of elements put together can do, we want each sample to present to designers how computation and responsive materials can give new characteristics to textiles.

After, Sample 1 was also presented. A small discussion followed about the sample and how it was made, especially the soft switches which are not integrated in the sample, but their function was demonstrated. A student wants to know whether the demonstration wires are necessary for the soft switches to work. The presentation of Sample 1 reminds the teacher of the work by e-textile designer Berzowska (Kukkia and Vilkas: Kinetic Electronic Garments, 2005). She again adresses the problem with attaching computing diveices on textiles. She states *"…devices are so big and clumsy and you see this more than you see the textile,… Still I think there is a lot of gimmick in it. In the beginning of an era then often the aesthetics go behind all the technology."* In relation to Sample 1 a comment from a student follows *"And also when you have all this gear… I really want something big to happen. And then it's just some very small things. It's very few things. And I'm thinking it must blow up. It must be firework… something. And they should do like this [imitating dramatic movement of textile]."* This is an important comment and an opposite view of that of the textile designer and Diffus which create the aesthetic part of the sample.

Part two

In this part of the survey students are asked to find use of the presented computational devices and responsive materials for different context areas. For the duration of 20 minutes they were working on developing the ideas. The atmosphare was relaxed and they all are very much engaged in their internal disscusions and the brainstorming of ideas. Few of them approached us to ask more questions relate to the materials we have presented. This might suggests their view on technology as an integral part of the design of objects that both combine computing, responsive materials and textiles.

Part three

This was a short part of the survey where the participants were asked to choose from a list of words to describe Sample 2.

Part four

This section describes the ideas given by the participants in regard to the concepts they have developed during their brainsorming session and also they give their commencts and views on samples presented.

They had several interesting ideas about how this new technology for them can be integrated with the textile:

"..we talked about, if you could print the solar cells on the tent, it would be more flexible and it would give more meaning to [the design of a tent for hiking]."

" …maybe these threats [referring to SMAs] should be integrated in the textiles so that the whole shape you can take up and down [referring to a bag which it can be made smaller]". Right after this another student comments on this:

"In my point of view, you can't talk about textiles like that. Because it's add-ons, and I don't think that's textiles. I think it's something you add on to the textile. And it's the textile that really matters in that context. I think it should be more integrated to be fascinating. To be… yeah… more innovative."

One of the participant mentioned that they did not like Sample 2 as it was "just adding light" while Sample 1 was more interesting because the textile was changing shape. All the suggestion until know where related to the designs which more or less we have heard before, like a wall changing patterns, or room divider. However few of those suggestions were very interesting and standing out from the

Student6: *Then we had like an ear flower or ear textile thing that could blow up when there is too much noise. And that could be customized for everyone in the country.*

Student5: *And then we also talked about the thing with the chairs in the window. Maybe cold… or something. And it can change shape when you have been sitting down all day and your bottom is soar… something new to sit on. And we talked about… switches… in the room. To make it blank instead of all these wires, so it could be more beautiful in a way.*

Student6: *Very light and transparent fabrics that didn't take up any space in the room. But could change color and become more or less transparent…*

Student5: *…Or light maybe?*

Student6: *Yeah. That's it I guess…*

Student5: *Oh, and we also talked about clothes like the girl from Canada [refering to Berzowska(2005)]. Something that can change to everyday clothes, but you can also go to a cocktail party later.*

Student6: *It rolls up, and you have it like a flashier outfit."*

The same students found the movements and the flexibility of the textile to be interesting to work with, as well they liked Sample 2 but implemented in some context, in some shape. They thought that the technology should be more integrated in the textile or totally exposed.

"But I also think that the technical part should be more integrated. Or totally exposed."

The survey finishes with a comment from the teacher regarding the workshop. She says that the textile design students learn in theory about wearables, however they do not practice it in their education. Furthermore, she says that it is very difficult to learn about computational devices from a workshop. She also refers to the workshop they had two years ago with e-textile designer Berzowska. She makes a point that it is hard to get something out from a workshop if you do not have the computational devices accessible as materials to put them in practice. With this the workshop was finished.

10.3 Feedback from the Product Reaction Cards

The feedback received from the third part of the survey (Product Reaction Cards) analyzed for the frequency of the most common adjectives used for describing the emotions connected with the sample material. The top three words here were:

1. Complex
2. Too technical
3. Unattractive

The feedback from the Product Reaction Cards suggests that the e-textiles were perceived as unaesthetic, with a high level of awareness on the technical parts.

11 Discussion

Both from the transcripts of the video recording and the written feedback (Product Reaction Cards) an overall impression is that the participants in the survey perceived the presented samples as complex and too technical. Furthermore they were very much aware of the existence of the technology embedded in the textiles, even though the textiles were presented as being aesthetical, physically hiding almost all the electronic and reactive elements, they still saw a great gap between their world of textiles and those of computation. Even though trying to bring the technology implementation's visibility to a minimum and apply new techniques for embedding computation in textiles, the participants of the survey were not able to pass the plastic and hard elements attach to the fabric. It is evident that their views on computation integrated with textile are very resistant, but this could have also been a problem of design, level of integration and interactivity. Our approach to the e-textiles as objects specially designed for textile designers could to some extend have been made differently. Giving a pretty façade to the base textiles, in order to hide the electronic parts, without a context in use, did not mean that it would trigger emotions of delight or surprise. Emotions and rich sensorial experiences are result of a person's perception of an object, created through interaction. Even though the textiles required some action on part of the users and were responsive to changes, what was missing was the context in which they were to be used.

On the other hand we can also argue that these materials were used as tools, a way to show what the technology can do, living up to the designer to find interesting ways of its integration. This could have been a good approach had we not hidden the technology and instead, used a design, which would dramatically present the full potentials that current computational devices and responsive materials have when embedded in textiles. This idea was further supported by the statement of one of the participants: "*And also when you have all this gear… I really want something big to happen."* This relates to another very interesting quote from the feedback: *"if the technology is not more seamlessly integrated, then maybe it should be totally exposed."*

The underlying topic during the survey's feedback sessions was the level of creativity of the term "creative integration". Based on this, although not verified data, we can still draw vague conclusions on how the survey participant perceived the samples. Analyzing the qualitative data it was clear that transparency could not be archived. Should true transparency possibly have had a chance to be created in the subconscious mindset of the test subjects, then a different type of test methodology (rather than a survey) should have been taken into consideration. As suggested by Mark Weiser, Phillips research, MIT creating transparency is a matter of embedding new devices into the culture of our everyday lives in a way so that we are no longer aware of their existence, solely enjoying the benefits of their capabilities. Creating transparency within this context was close to impossible, as embedding technology as part of textiles is still not part of our everyday Western culture. Thus to many people this idea still seems too science-fiction like and futuristic. Many traditional textile designers belong to this group. They do not see a reason why this integration should even be made, referring to the teacher-participant in the survey, questioning both our work on the samples and that of the designer Berzowska.

Even though, the group consisting of eight textile students and their teacher to some extend could be described as “expert users”, they had not been exposed to the ideas of combining technology with textile, on a sufficiently high level allowing us to say it had become an integrated part of their culture. Actually this idea was all very new to them. As stated earlier, the groups’ most familiar medium for design expression was plain textiles; that is without the “e” for e-textiles. Also the survey participants had no working practice from the fields of e-textiles and human-computer interaction. Due to these facts perhaps the best term to describe the subjects of our focus group in relation to e-textiles and HCI is therefore “novice users”. Evidently therefore, in the eyes of the survey participants, the technology present in the textiles was everything but creatively integrated and transparent.

Thus it is understandable why many do not yet see reasons for coupling of computation, responsive materials and textiles. The research field of e-textiles is still in its infancy and many of the projects we have seen are very basic in their functions, or still on the conceptual stage. Technologically we have not advanced to a point where computation is seamlessly integrated with the environment. Nevertheless this should hold back designers from exploring this new research area, especially as part of a multidisciplinary team.

A suggested system for further investigation of the textile designers’ perception of transparency will require detailed investigation in the form of an ethnographic study of their working culture and how they relate to the materials they work with. As suggested by the teacher a workshop in its own is not enough for textile designers to learn about integration of computation and textiles; especially, if they themselves are not able to practically gain experiences within this field. Future development of the samples requires a larger quantity of participant and a broader scope of time in order to truly understand textile designers and how they work creatively developing samples.

As seen in Phillips’ HomeLab test, where subjects in the environment of a home, are exposed to adaptation of new hidden ambient intelligence devices, it is evident that true transparency can only be created with time. Looking at another example: Martin Heidegger ready–to–hand where a hammer is perceived as hammer when located in the toolbox, while when in use it is no longer perceived but a mere extension of the self, it can also be argued, evaluating the transcribed feedback that was collected during the survey, that having placed the samples on a table in the middle of the classroom, it didn’t serve the purpose of creating technological transparency. Only in use and in the right context a hammer becomes the extension of the self. The same most likely goes for the materials used in the survey. Furthermore it’s also a question of cultural adaptation, that the “hammer” is perceived as such. A Neanderthal would probably perceive it differently. Hence it can be argued that with the short scope of time assigned for this project, proper testing of the validity of the three hypotheses examining the samples’ level of transparency would have been quite difficult (if not impossible) to achieve.

Only with time can transparency occur, as new items need to move from the center of attention towards the periphery of our minds before we can argue they have disappeared from our consciousness. Should this ever become a reality, we first need to review the culture in which we live in. Whether “novice” or “expert” users, perhaps only when ubiquitous computing has become the dominant paradigm in HCI, we can truly start investigating transparency of the technology. Until then, reaching more than a high level of creative integration within the culture we live in seems nothing more than a utopian thought. The best shot we have at surveying true transparency versus creative integration is done in small bubble cultural paradigms as created in the Phillips HomeLab tests. Changing people’s culture cannot be done in a one-hour classroom survey. But still, it can, and did, teach us a lot.

By the same token, we can argue that an electrical bulb would create furor and great excitement had a group of aborigine tribesmen been beamed (as we have so often seen in Star Trek) to a room in which the only present device would be a switch on the wall and electrical bulb in the ceiling. Had a westerner been exposed to this setup he would most likely, after a few long seconds of boredom, plainly leave the room without attaching greater thoughts to it. Phillips’ HomeLab is the room with the bulb and we are the tribesmen, and it’s this kind of environments and test setups we need to use should we really test for, validate and verify transparency versus creative integration. Without these small mini-cultural bubble setups we can at the best hope for a bit of useful feedback, exactly as the data collected from our one-hour classroom survey.

For that reason we can conclude that we did not manage validating the truth of our three hypothesizes. Still the one-hour survey proofed a success. We learned a great deal from the survey, such as creating true ubiquitous computing devices as e-textiles, takes more than creatively trying to integrate electronic devices on different kinds of materials. As transparency is not as much physical as it is psychological, perhaps what it really takes is a whole cultural change in which we as humans get so much used to smart devices, computing by the Inch, Foot and Yard, that we stop being aware of the technology, but instead solely perceive the artifacts surrounding our lives as a natural extension of the self. Culturally we are not there yet. This was also suggested by analyzing the results from our survey.

12 Conclusion

As stated previously, the aim of this project was to examine the intersection of computation with traditional textiles, and understand how their integration is perceived by textile designers as means for creative expression. This statement was reached after doing extensive research in the concept of ubiquitous computing narrowing down to the area of e-textiles; still and area within the field of ubiquitous computing. The focus was placed on traditional textile designers and their resistance towards integrating computational and electronic devices with textiles. In order to bring the world of computation closer to them, an *Interaction Book Sample* was proposed as a tool; helping designers to unveil the creative possibilities arising from coupling textiles and computation, which until recently have never been integrated together. In order to get a better understanding how textile designers view computation being embedded in traditional textiles, a qualitative survey was conducted with nine participants. The survey gave an insight into possible new directions on of how e-textiles can be developed further. For sound data and proof of validly further investigation is needed though. This empirical data could possibly be collected in the form of a testing environment such as used by Phillips in their HomeLab study.

12.1 Future perspectives

The development of the remaining sample will continue in the coming months. The Interactive Book Sample seems to be well accepted in the design community. It has already been presented to one workshop in Strasbourg, France and at a design conference in Kolding, Denmark. The Interactive Sample Book will be presented at the TechTextiles Fair, from the 15-17th of June 2009 in Frankfurt, Germany and the Smart Textiles Salon[36], a joint European Workshop, on the 25th of September 2009 in Ghent, Belgium. The positive feedback on the sample book suggests the need for establishing a framework, standards and methods for building e-textiles that can empower designers to make wearable products for the general public, which are both stylish and functional. Nevertheless, many aspects in the concept and design of the current Book Sample need to be revised. New methods for presenting computational technology and responsive materials are needed to make this book approachable to designers and to make computational technology more accessible.

[36] www.smarttextilessalon.com

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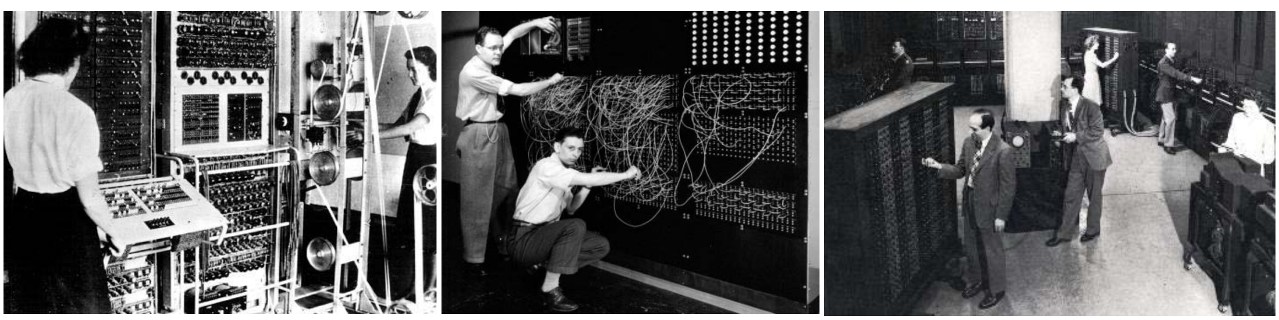
14 Appendix A: A Brief History of Human-Computer Interaction

14.1 The electrical HCI paradigm

The first major paradigm in which we can argue computers, in a somewhat familiar shape, played a role was what is referred to as the electrical paradigm. True, in earlier periods the word “computer” meant “one who computes” and it referred to people whose job it was working on mathematical calculations such as engineering tables, but with the emergence of the analogue electrical computer this changed, and now machines and not humans were referred to as computers. The analogue machines of the electrical HCI paradigm ran on standard components such as vacuum tubes, punched paper tape and thick wires. They were big and clumsy and could easily take up all the space in a large room. Also the way humans perceived them back then was much different than today, with a less clear boundary between what we now know as hardware and software. Working and interacting with them was not about simply pressing a button and letting the machine take care of running the executable, but much more a tedious and complicated task that only few well educated scientists and research staff that knew how to accomplish.

Good examples of such machines are the Harvard Mark-1 designed and built by IBM, the Colossus, which was used by the British armed forces in during World War II by the code breakers at Bletchley Park in 1944, who used it for decrypting and interpreting secret German messages[37] and last but not least the ENIAC from 1946, which was the first general-purpose electronic computer. As with many other inventions from the time around World War II, also the ENIAC was used by the military. It was designed and constructed to calculate artillery firing tables for the U.S. Army's Ballistic Research Laboratory.



Pictures: Left: One of the first computers. The Colossus used in Bletchley Park. 1944. Middle: Harvard Mark-1, a room-sized relay based calculator built by IBM. It was used to produce tables. 1944. Right: The

[37] www.bletchleypark.org – 25.02.2009

ENIAC from 1946, which was programmed using plug boards and switches. Input/output was done by cards, lights, switches, plugs. It could perform 5000 operations per second, which was already 1000 times the speed of its contemporaries[38].

14.2 The Symbolic HCI Paradigm

During a time span of around 15 years, starting in the mid 1940'ies until around 1960, companies such as IBM and governments alike competed against each other building faster computers, all of them dependant on the few capable researchers and technical staff skilled enough to understand and work with the complex input/output electronic mechanisms defining the computer's language. In 1957 a shift in communication and interaction started occurring with the introduction of IBM's revolutionary programming language FORTRAN (short for FORmular TRANslator). FORTRAN, which was developed based on the compiler language concepts of mathematician Grace Hopper was a replacement of the old days' electronic human-computer plug boards and punch card interactions and gave way for a the next paradigm: The symbolic paradigm, in which communication takes place by using easier understandable and intuitive symbols such as the IF statement, GOTO, ASSIGN, DO, PAUSE, STOP and CONTINUE. By 1960, even though punch cards were still used, FORTRAN was made available on several IBM systems and by 1963 more than 40 different FORTRAN compilers existed. By that time, electrical human-computer interaction was very much beginning to look like an artifact of the past. Together with the introduction of FORTRAN combined with lower manufacturing costs, the computer had become a more widespread phenomenon. In terms of quantity, computers were no longer counted by the tens but now by the hundreds. Even though, by now computers had become a global phenomenon, they were still only accessed by the few, who worked in computer science. In shape they were still as big, clumsy (and everything else than invisible) as their predecessors. In all means we were still very far from the vision of the ubiquitous computer.

14.3 The Textual HCI Paradigm

As a direct continuation of the previous periods' forthcoming FORTRAN language, computer manufacturers were starting to rely more heavily on textual based human-computer interaction. Programming languages were steadily becoming capable of performing more complex calculations, and it

[38] www.computerhistory.org – 19.02.2009

was becoming clearer to the thousands of computer users around the world, that communication was not only made by the use of a couple of words, but via command lines based on different logic, that formed different rules of "grammar". New programming languages such as COBOL, LISP and BASIC were born, and humans now "talked" to computers using textual "dialogue" rather than just few words. Building upon earlier days' success with creating constantly more intuitive programming languages, the first object-oriented programming language saw the light of the day: Simula, written by the Norwegian computer scientists Kristen Nygaard and Ole-John Dahl in 1965[39]. In 1969 AT&T Bell Laboratories developed the UNIX operating system, a programming language still widely used on servers today. In 1981 Microsoft launched its MS-DOS for the newly released IBM personal computer, and in 1985 Bjarne Stroustrup published the C++ programming language, largely inspired by Nygaard's and Dahl's Simula language. Computers, which until then had mostly been accessed by scientists, were now slowly finding their positions in offices, libraries and universities, use by non-technical students, librarians and hobby programmers.

Pictures: Left: The popular Apple II from 1977. Middle: The Commodore 64, which was introduced at low price of $595 featured impressive graphics and ended up selling more than 22 million units. It was later recognized by Guinness Book of World Records as the most sold computer model of all times (1982). Right: Apple's Macintosh graphical user interface featuring a desktop and icons (1984).

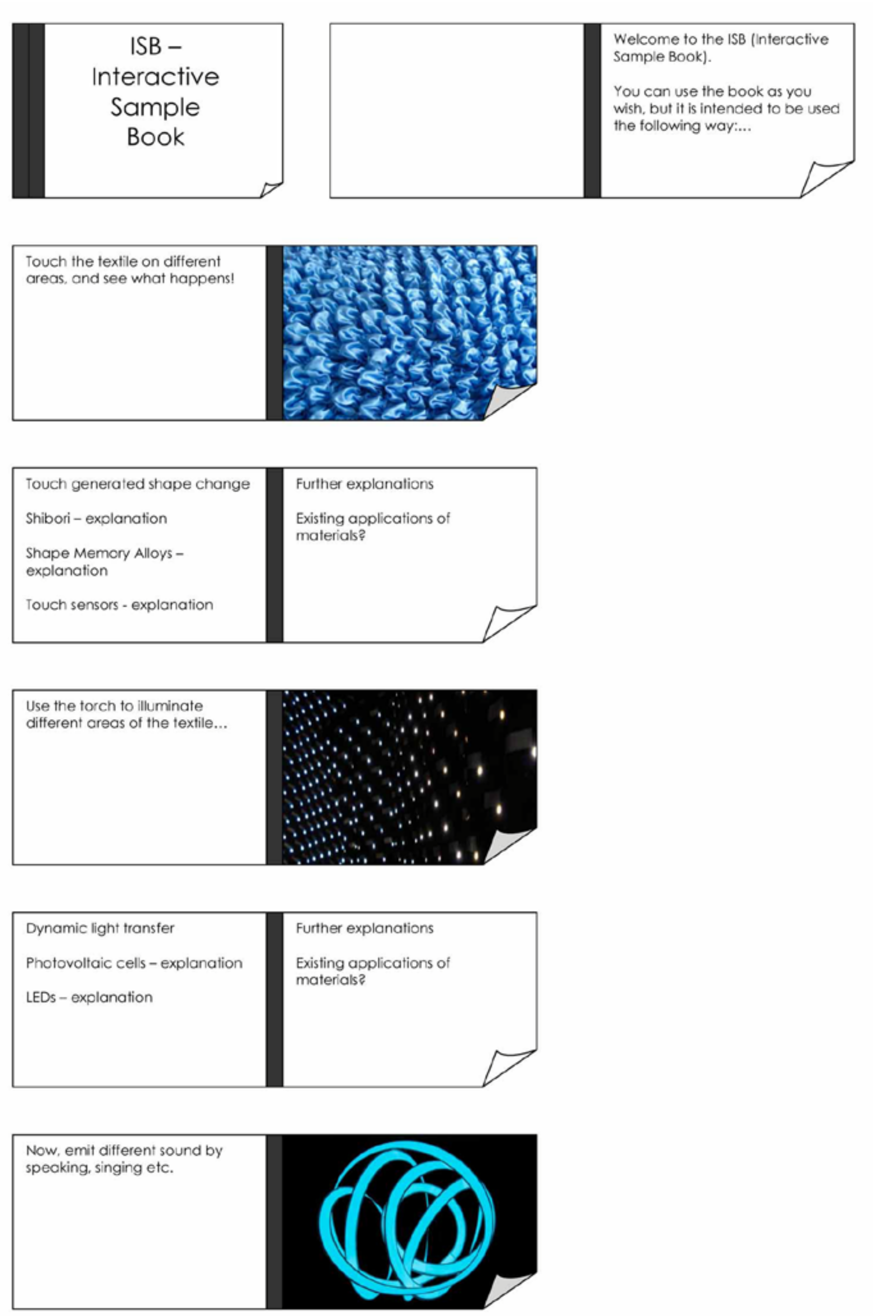
14.4 The Graphical HCI Paradigm

We are now in the early 1980'ies. Together with the development of the graphical user interface, with well-known graphics such as icons, scroll-bars and menus a new kind of human-computer interaction

[39] www.computerhistory.org - 22.02.2009

paradigm was emerging: The graphical HCI paradigm. Computers were becoming a mainstream commodity, and no longer used solely by large corporations, military and government institutions, but as well by architects, designers and ordinary people, such as teenage gamers using their PC for games such as Atari's Pong (1972), Sim City (1989) and Doom (1993). The paradigmatic shift from textual to graphical based human-computer interaction did not simply replace words with icons. It opened up for a whole new two dimensional universe - a universe in which humans perceived the computer in a much different way than before. Computers had become objects many people could relate to, and soon it was not uncommon even owning more than one of them. Computers were everywhere, and more visible than ever before, especially when looking at people's desks. That's how it still is in today's world, and it can well be argued that the graphical human-computer interaction paradigm is, and will, stay dominant for many years ahead. However with the emergence of the many desktop computers, known as PCs, another kind of computer started finding its way into our lives and together with it a new paradigm was taking shape. In 1988 Mark Weiser, the chief technology officer at Xerox's Palo Alto Research Center, coined this paradigm ubiquitous computing.

15 Appendix B: Initial Idea for the Interactive Sample Book



Sound responsive light

Electroluminescent wires – explanations

Piezoelectric sensors – explanations

Further explanations

Existing applications of materials?

Pull the elastics…

Colour change as memory for heat and light

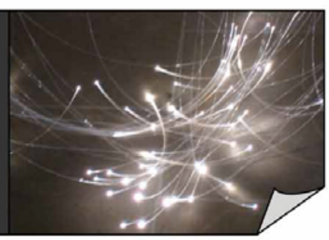
Heating conductive threads – explanations

Thermo chromatic inks – explanations

Further explanations

Existing applications of materials?

Move your hand above the fabric



Movement responsive sound & light

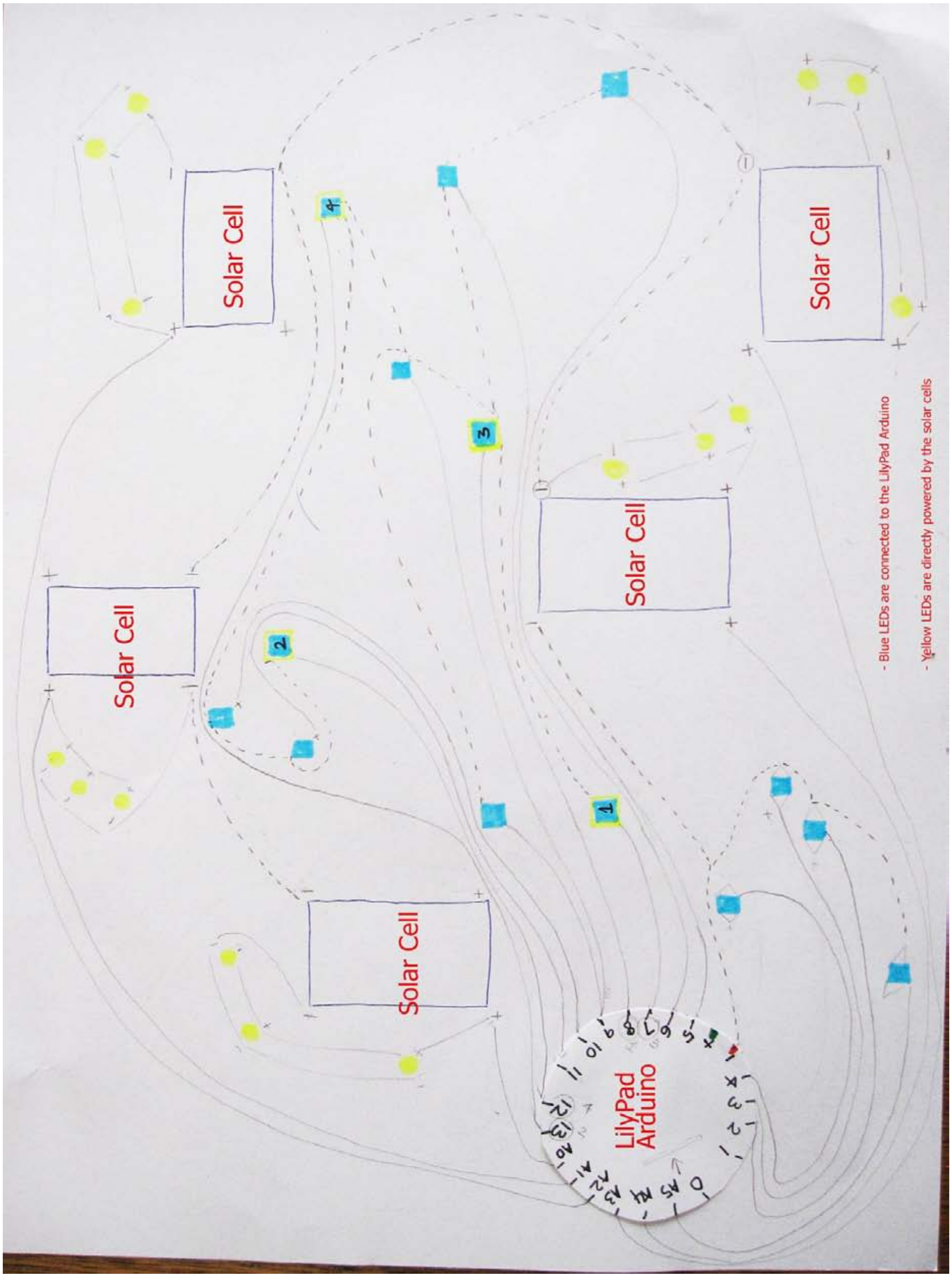
Optical fibres – explanations

Further explanations

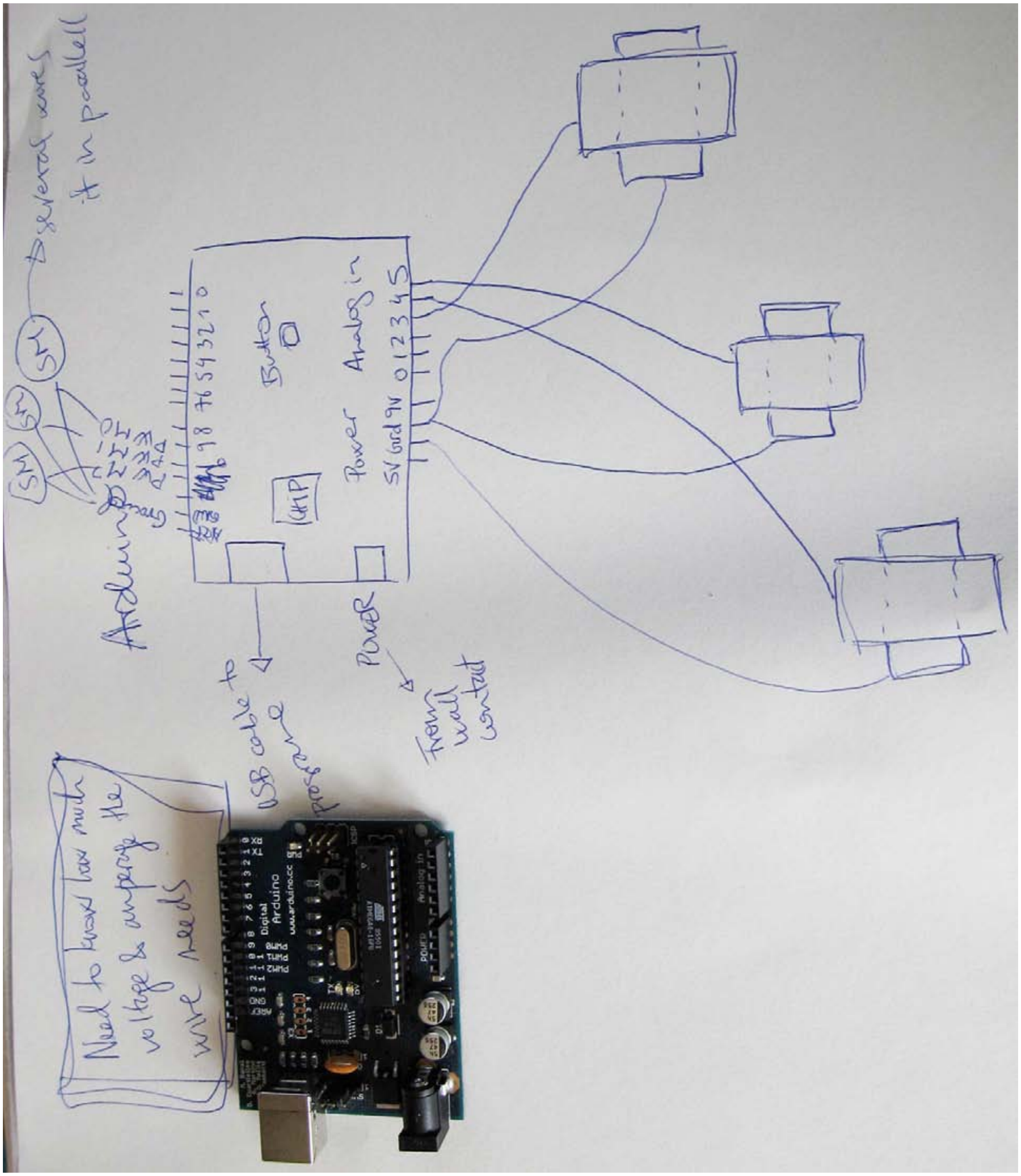
Existing applications of materials?

The End – or rather the Beginning!!!

16 Appendix C: Overview of the Circuit for Sample 2



17 Appendix D: Overview of the Circuit for Sample 1



18 Appendix E: Code for Sample 2

```
/* sketch for activating a pattern of LEDs every time a solar cell is powered by pointing a light torch */

int curSensorValue[] = {0,0,0,0,0};

int lastSensorValue[] = {0,0,0,0,0};

int state[] = {2,2,0,0,0};

long lastStateChangeTime[] = {0,0,0,0,0};

int leds[] = {2,3,4,5,6,7,8,9,10,11,12,13,19}; /* array of all leds */

int noPWM[] = {2,4,7,8,12,13};

int activeLedPin = 7;

int oldSensor = 0;

int oldState;

int newState;

int lightIntensity = 0;


/* activeLeds[i][j] gives you the leds that should be turned on for sensor i, when it is in state j */

int activeLeds[5][3][7] = {


/* 3 patterns of LEDs for each solar cell

 { /* Sensor 0 */

   {9,2,12,13,-1,-1,-1}, /* State 1 */

   {10,4,13,-1,-1,-1,-1},

   {11,8,5,2,6,-1,-1}
```

```
  },
  { /* Sensor 1 */
    {5,6,13,6,-1,-1,-1}, /* State 1 */
    {2,7,11,9,13,5,-1},
    {4,3,8,11,12,-1,-1}
  },

  { /* Sensor 2 */
    {10,3,5,6,2,-1,-1},
    {11,4,13,12,7,9,-1},
    {12,3,19,2,5,-1,-1}
  },
  { /* Sensor 3 */
    {12,10,2,4,6,-1,-1},
    {13,3,9,11,8,5,-1},
    {3,9,10,7,19,-1}
  },
  { /* Sensor 4 */
    {4,8,5,6,19,11,-1},
    {3,12,19,8,9,6,2},
    {6,8,13,12,4,9,-1}
  }
};
```

```
void setup()
{
        Serial.begin(57600);              //initialize the serial port
        pinMode(2, OUTPUT);           // declare the ledPin as an OUTPUT
        pinMode(3, OUTPUT);
        pinMode(4, OUTPUT);
        pinMode(5, OUTPUT);
        pinMode(6, OUTPUT);
        pinMode(7, OUTPUT);
        pinMode(8, OUTPUT);
        pinMode(9, OUTPUT);
        pinMode(10, OUTPUT);
        pinMode(11, OUTPUT);
        pinMode(12, OUTPUT);
        pinMode(13, OUTPUT);
        pinMode(19, OUTPUT);
}

//fadeIn function
void fadeIn(int curLed) {
  int lightIntensity;
  for(lightIntensity=0; lightIntensity<=255; lightIntensity+=5)
```

```
 {
   analogWrite(curLed, lightIntensity);          // sets the value (range from 0 to 255)
   delay(30);                          // waits for 30 milli seconds to see the dimming effect
 }
}
//fadeOut function
void fadeOut(int curLed) {
 int lightIntensity;
 for(lightIntensity=255; lightIntensity>=0; lightIntensity-=5)
 {
   analogWrite(curLed, lightIntensity);     // sets the value (range from 0 to 255)
   delay(30);           // waits for 30 milli seconds to see the dimming effect
 }
}
void setLightIntensity(int curLed, int lightIntensity) {
     int j;
     int curLedHasPWM;
     curLedHasPWM = 1;
     for (j=0; j<6; j++) {
       if (curLed == noPWM[j]) {
         curLedHasPWM = 0;
         break;
       }
```

```
    }
    if (curLedHasPWM) {
      if (lightIntensity == HIGH) {
        fadeIn(curLed);
      } else {
        fadeOut(curLed);
      }
    } else {
      digitalWrite(curLed, lightIntensity);
    }
}
void loop()              // run over and over again
{
  Serial.println("in loop");
  int i;
  int sensor;
  int curLed;
  int stateShouldChange = 0;

  //read every second
  if(millis() > 1000 + lastStateChangeTime[i]){
  /* Read new values from the sensors */
    for (i=0; i<5; i++) {
```

```
  lastSensorValue[i] = curSensorValue[i];
  curSensorValue[i] = analogRead(i);

  /*
  Serial.print(i);
  Serial.print(": cur_val = ");
  Serial.print(curSensorValue[i]);
  Serial.print(", prev_val = ");
  Serial.println(lastSensorValue[i]);
  */
 }
}
/* Change the state when the light is being turned on (but only once per second) */
stateShouldChange = 0;
for (i=0; i<5; i++) {
 /*
 Serial.print("lastStateChangeTime: ");
 Serial.println(lastStateChangeTime[i]);
 Serial.print("milis: ");
 Serial.println(millis());
 */
 if (curSensorValue[i] > 400 && lastSensorValue[i] <= 400 && millis() > 1000 + lastStateChangeTime[i] ) {
  //turn off all leds before new pattern
```

```
    for(int output_pin=0; output_pin<13; output_pin++){
      digitalWrite(leds[output_pin], LOW);
    }
    lastStateChangeTime[oldSensor] = millis();
    stateShouldChange = 1;
    sensor = i;
     lastStateChangeTime[sensor] = millis();
    break;
  }
  //if sesor current goes down (meaning no light) turn everything off
  else if(curSensorValue[i] < 400 && lastSensorValue[i] >= 400 && millis() > 1000 + lastStateChangeTime[i]){
    for(int output_pin=0; output_pin<13; output_pin++){
      digitalWrite(leds[output_pin], LOW);
    }
  }
}
if (stateShouldChange) {
    oldState = state[oldSensor];
    state[sensor] = state[sensor] + 1;
    if (state[sensor] > 2) {
      state[sensor] = 0;
    }
    newState = state[sensor];
```

```
Serial.println("##################### We are now in state:");
Serial.println(newState);
Serial.println("of sensor:");
Serial.println(sensor);


/* Turn off leds from the old state */
Serial.println("Old state:");
Serial.println(oldState);
Serial.println("Old sensor:");
Serial.println(oldSensor);
for (i=0; i<7; i++) {
  curLed = activeLeds[oldSensor][oldState][i];
  if (curLed != -1) {
    Serial.println("turning off led:");
    Serial.println(curLed);
    //only when light sourse is on should we turn off leds from previous pattern
    //setLightIntensity(curLed, LOW);
  }
}


/* Turn on leds */
for (i=0; i<7; i++) {
  curLed = activeLeds[sensor][newState][i];
```

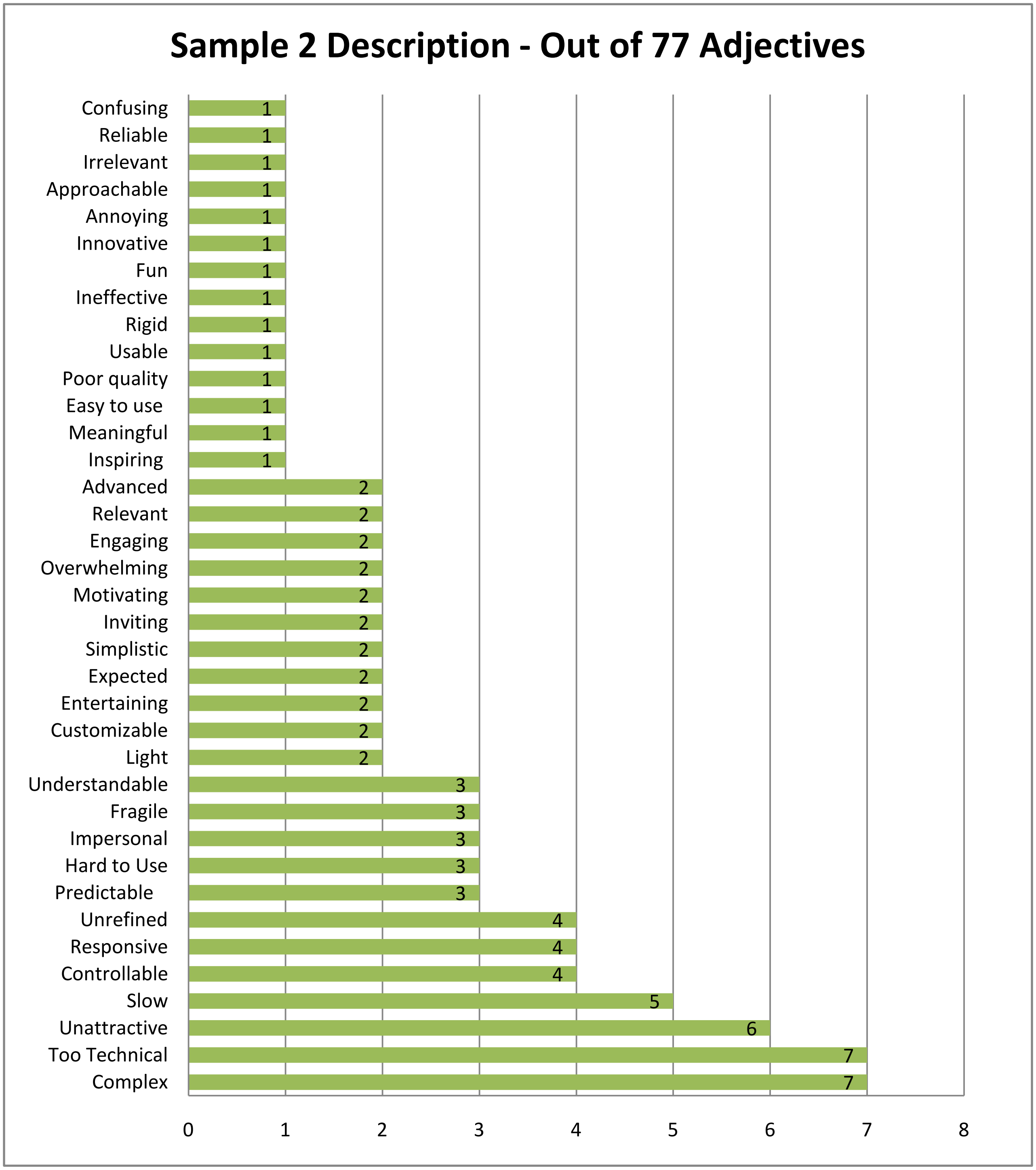
```
      if (curLed != -1) {
        Serial.println("turning on led:");
        Serial.println(curLed);
        setLightIntensity(curLed, HIGH);
      }
    }
    oldSensor = sensor;
  }
  delay(1000);
}
```

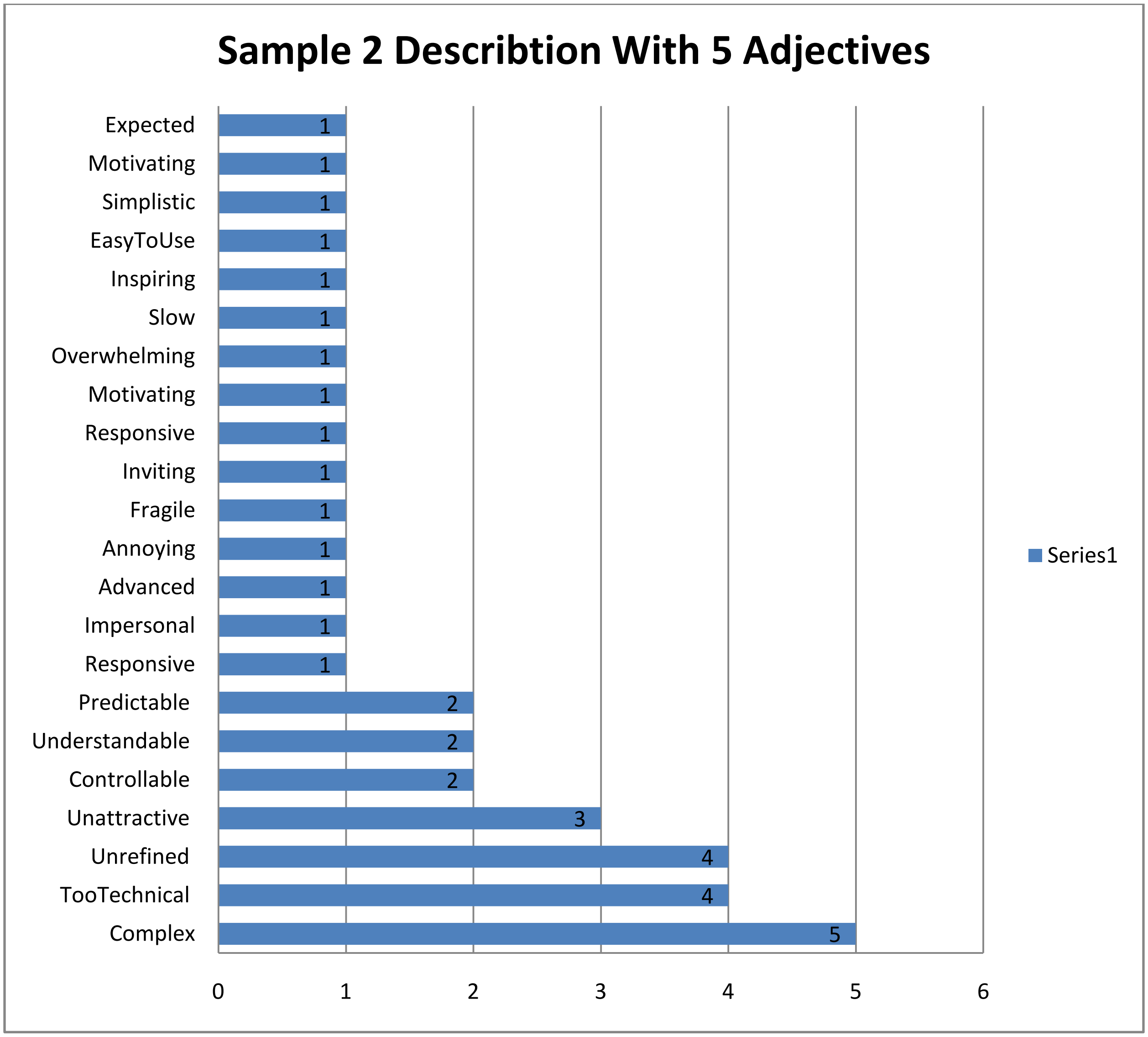
19 Appendix F: Product Reaction Cards Adapted for the Survey

Step 1: Read over the following list of words. Considering the textile you have just seen, tick those words that best describe your experience with it. You can choose as many words as you wish.

- ☐ Accessible
- ☐ Valuable
- ☐ Inspiring
- ☐ Appealing
- ☐ Intuitive
- ☐ Attractive
- ☐ Boring
- ☐ Complex
- ☐ Light
- ☐ Meaningful
- ☐ Convenient
- ☐ Not secure
- ☐ Customizable
- ☐ Novel
- ☐ Desirable
- ☐ Ordinary
- ☐ Dull
- ☐ Easy to use
- ☐ Poor quality
- ☐ Empowering
- ☐ Predictable
- ☐ Entertaining
- ☐ Usable
- ☐ Expected
- ☐ Rigid
- ☐ Flexible
- ☐ Simplistic
- ☐ Fresh
- ☐ Ineffective
- ☐ Fun
- ☐ Hard to Use
- ☐ Too Technical
- ☐ High quality
- ☐ Impersonal
- ☐ Old
- ☐ Frustrating
- ☐ Innovative
- ☐ Annoying
- ☐ Integrated
- ☐ Intimidating
- ☐ Approachable
- ☐ Inviting
- ☐ Irrelevant
- ☐ Low Maintenance
- ☐ Controllable
- ☐ Motivating
- ☐ Creative
- ☐ Not Valuable
- ☐ Cutting edge
- ☐ Impressive
- ☐ Distracting
- ☐ Overwhelming
- ☐ Personal
- ☐ Effective
- ☐ Powerful
- ☐ Engaging
- ☐ Relevant
- ☐ Reliable
- ☐ Responsive
- ☐ Familiar
- ☐ Satisfying
- ☐ Fragile
- ☐ Slow
- ☐ Sophisticated
- ☐ Stable
- ☐ Stimulating
- ☐ Straight Forward
- ☐ Stressful
- ☐ Helpful
- ☐ Unattractive
- ☐ Understandable
- ☐ Undesirable
- ☐ Unpredictable
- ☐ Unrefined
- ☐ Exiting
- ☐ Advanced
- ☐ Confusing

Step 2: Now look at the words you have ticked. Circle five of these words that you think are most descriptive of the textile and write them on a post-it.


Sample 2 Description - Out of 77 Adjectives
Confusing 1
Reliable 1
Irrelevant 1
Approachable 1
Annoying 1
Innovative 1
Fun 1
Ineffective 1
Rigid 1
Usable 1
Poor quality 1
Easy to use 1
Meaningful 1
Inspiring 1
Advanced 2
Relevant 2
Engaging 2
Overwhelming 2
Motivating 2
Inviting 2
Simplistic 2
Expected 2
Entertaining 2
Customizable 2
Light 2
Understandable 3
Fragile 3
Impersonal 3
Hard to Use 3
Predictable 3
Unrefined 4
Responsive 4
Controllable 4
Slow 5
Unattractive 6
Too Technical 7
Complex 7
0 1 2 3 4 5 6 7 8


Sample 2 Describtion With 5 Adjectives
Expected
Motivating
Simplistic
EasyToUse
Inspiring
Slow
Overwhelming
Motivating
Responsive
Inviting
Fragile
Annoying
Advanced
Impersonal
Responsive
Predictable
Understandable
Controllable
Unattractive
Unrefined
TooTechnical
Complex
1
1
1
1
1
1
1
1
1
1
1
1
1
1
1
2
2
2
3
4
4
5
0
1
2
3
4
5
6
Series1

20 Appendix G: Transcription of video material

(Date recorded: 26th May, 2009)

Participants:

Eight textile designers and a teacher from the Danish Design School - Copenhagen

&

Elisabeth Heimdal and Marija Andonovska

Note: Transcription is made to most of the conversion in the video (can be found on the DVD attached to this thesis). Few small sections are not included as a result of a bad sound quality of the recording.

Time: 0:00 – start of scene 1

Teacher: How could it be? I mean when it's not using the sunlight but a lamp that is also electricity. It's the other way around.

Heimdal: Yeah exactly, but I think we did that because we didn't want to be dependent on sunlight when we showed it to people. And we use, actually, this solar cell both as a sensor, so that it's a sensor saying, ok now there is light, now you have to activate it. And it also gives power directly to some LEDs located close by. But my initial idea was to make it a textile that you could hang in the sun, then take inside, and then light up. Then we thought ok but what then if there is not enough sun, and so on. And so we wanted more to give, yeah, to give a person a possibility of creating something himself. Even though it's, you could say, it's artificial to have a lamp and to imitate the sun… ehm… maybe some of you would like to try it a little bit.

Teacher: So what you said, is that the little computer is programmed so that if you have been in this one before you come here, it will do differently than if you were here before?

Time: 1: 18

[Students trying out the sample]

Student: And then this threat makes this connection?

Heimdal: Yeah, this makes the connection. And then this is also another kind of threat, which can be used to make the connections.

Teacher: What is it made of?

Heimdal: It's made of a blend of nylon and silver, I think, or another metal. And, this one is really easy to sow it. It's like. It's like a normal threat. But it's very… so when you use it, it's going apart. We also had problems when the batteries go out of this, there is still light, but it's not strong enough, so we think it's not working, because there is not enough light.

Teacher: So still it was just for try out. Just an application to examine…

Time: 2: 42

Heimdal: No, and the goal, you can say, it's the same for all these materials. They don't have a function or an application in themselves. They are just supposed to show something. Show what you could create when there are these kind of materials. And when we showed this earlier to architects and other designers. Some of the feedback we got was that, why do you have this thing on top here. Why don't you just show… because this circuit is beautiful. And then you can actually see what happens. Because then when you see this you might think, there are all electrical wires inside. But we made it together with a textile designer, and she wanted to do it like this. And she colored this herself to imitate the night sky. She was inspired by a special picture and so on. So it was like.. yeah, the pros and the cons. Do you want to show the technology, or do you want to hide it? Do you want to use it as something aesthetic or…

Student: And these solar cells, are also really… they are not textile of course, but they are totally bendable…

Heimdal: Flexible… yeah.. You can see there is a picture of them there. They have like a… surface. And they were really. Easy to handle.

Time: 4: 22

Teacher: So what do you think about this complex thing about showing the technology and integrating it in a way that is visible and…eh

Heimdal: I think it would. I think I would like to remove this now. But I was afraid maybe that someone might not like it. Someone would not think it's beautiful or… yeah. There is a picture there, where you can see the whole thing without top fabric. And then you can see all the LEDs because the LEDs have two long legs, and we had to curl the legs up like this and sow it and so on.

Time: 5:14

Andonovska: But if I can say something about your question. I think that current electronics are not really made for textiles. And when they design them they don't really consider these things, how to make them look maybe nicer or feel more flexible and so on. The LilyPad that we have used there is especially made for textiles. So it looks really pretty as well to look and to integrate it with design.

[Heimdal and students discussing materials]

Time: 6:34

Teacher: Because I think that's some of the problems about this new type of technology. In a way it's difficult to say, why should it go on textiles. What's the idea? If it's like still getting this contrast is so big.

Heimdal: Yeah. The contrast between the textile and the solar cells…

Teacher: Yes. And also perhaps because it's like a square piece. You see it… Is it a picture? Is it? It has in a way no application to textile except it is a textile material. They look a bit…

Andonovska: They have actually made them soft and flexible. The woman that has made the LilyPad, she also made a flexible LilyPad that was made out of material. But for mass production they just made plastic if you can say. But otherwise that one was very much flexible, made of conductive materials, which we have some of them over there. You can see.

Heimdal: But I think that's also what I would like to have your input on. And that's why I wanted you to come, that maybe you can, based on this, I would ask you later… How can this be used in a different context? And what I think is interesting about integrating technology in textiles is that textiles is something that is really intimate to us. And textiles are so different from most other materials. Like a mobile phone and computer it's all about boxes… or like a light source, which is just a point. And if you could make something of that in textiles you could make it in many different ways. If you have a light source, which is more like a surface. I think about elderly people. I think about my grandmother. She doesn't like here phone. But she is maybe very comfortable with her jacket or whatever it is. So there is… I think there are some possibilities that I would just like to try to explore.

Time: 8:58

[Light is being turned on in the room. Discussing now next material]

Heimdal: So this is the next sample we made. And on this one we worked with shape memory wires. I don't know if you know about that. But it is a kind of metal, which you can heat up. If you heat it to like 700 degrees you can give it a shape like a spiral or anything. And then you can stretch it out again. And then when you give current to it. When you apply power to it, then it remembers it's shape. So it's going to go back to its shape that it had in the oven. And so the idea here was to try to make some, create some movement in the textile using that. And this is not the best power source but I will try to make it work.

[Heimdal applying the power source to the sample material]

Time: 10:13

Heimdal: So we have just programmed this wire, and then we have sewed in on to the textile…

Teacher: What did you program?

Heimdal: We have programmed a zigzag shape, which is closer than this one... So now the zigzag is kind of stretched out.

Teacher: Not programmed digitally. But just curled and heated.

Heimdal: Curled. Yeah.

[Heimdal demonstrating sample]

Heimdal: And this is not the best power source. We don't… Actually it can contract even more. But so this is the idea. This is what we want to make. Want to make it contract this much. And this sample is actually not finished the way it is. Because just as in this one [pointing at first sample material] we want them to be some input so that a person has to do something. And in this one [pointing at sample first sample material] it was to hold a light. And in this one [pointing at second sample] what we want the person to do is to touch so we want the person to touch the textile on some points, and this should activate this one. And to do that we have used some copper fabric, which is conductive so that it conducts electricity. And you have. There are a lot of these. All these are conductive fabric in different kind of materials. But we have used this one, and so the basic idea is that we want to take one fabric and then another one and then another one, and we put a thick fabric in between which has a hole in the middle. So when it's like this there is no contact and when you push there is contact. And so that is what we have been working on here. So all these are areas where there could be contact. I will try to demonstrate that as well.

[Heimdal demonstrating sample material]

Time: 13:22

Heimdal: So this is. This is a button. Just like the button like you have on the wall… this is just a textile button. And so then the way we want to do this is that we want to make some layers under this conductive fabric and to make maybe one button here, one there, and so on. And then connect it to the same kind of LilyPad so that the LilyPad again triggers these…

Andonovska: Gives power.

Heimdal: Yeah gives power. Yeah.

Student: But do you need all these wires as well?

Heimdal: No no no. Actually what we will do is, that we will use this. So that we will take one here, and one here. And take them out. Maybe on top or underneath. And then make the same kind of system as for that one. And when we developed the idea for this we were thinking it's a textile, which is live. Like, you touch it then it moves. Or something like that. This is what I can show you now. We worked with different shapes. You could imagine any kind of movement. This is just. This cutting here, kind of maximizes this little here. But we also worked with textiles closing like this. If you have a circle like this or… if you have a cut out here, that there is something lifting up. We found this one more interesting. Because it maximized what happens…

Time: 15:09

Teacher: You know the Canadian Joanna Berzowska who have been working on these conductive. She has made flowers that suddenly would like do this. Do that. But the thing is that it doesn't just go back. You have to draw it back so. She also made a dress that was a longer dress. And then it would go shorter when it… so… you had to take it down. But some of the problems is still… that some of the devices are so big and clumsy and you see this more than you see the textile, and the textile become. Still I think there is a lot of gimmick in it. In the beginning of an era then often the aesthetics go behind all the technology.

Student: And also when you have all this gear… I really want something big to happen. And then it's just some very small things. It's very few things. And I'm thinking it must blow up. It must be firework… something. And they should do like this [imitating dramatic movement of textile].

Heimdal: Yeah. But it's also something that we have been working on. Because we have made tests with this. We had another shape which was spiral. And then it was really like. The whole thing was really dramatic. Then I worked with Diffus. And the two at Diffus were like it's too much. It's too much. It needs to be more organic. More subtile. Like you don't see it immediately. And so it's so all this. I think this project is a little bit about thinking, and we have trying to think all the time, how do we get away from the gimmick. How do we get away from the demo, just like to do something else with it.

Teacher: So these are the two main technologies you have been using?

Heimdal: Yeah. Yeah.We have made five concepts, but we have been working on three of them. The third of them, which is a textile, reacted to sound, by emitting lights. And for that we used some electro luminescent wires. I don't know if you know that. It's like a plastic wire and it has a material inside, which lights up. It can be blue or white or… and we would like it to like pulsate with sound. But again it's something about an electronic device that is measuring the sound and reacting and then triggering something that is integrated into the textile. Ehm… Do have anything more to say though?

Students: No

Time: 18:01

Heimdal: And for this one [pointing at first sample]. The one we made the furthest. Here is like an explanation. So where I take the different parts, the LEDs, the optical fibers, the LilyPads and solar cells. I take all these parts and just explain a little about it. And here you see maybe what's more interesting it's some projects that has been made with these kind of things. To the left it's projects with the LilyPad. And on the right it's projects just with solar cells and LEDs. So it's not necessarily textiles, but it's just using those kind of technologies. And using the softness in these flexible solar cells. Do you have any more questions about these, or reactions, or thoughts or anything?

Student: How long have you been working on, and when should it be finished?

Heimdal: I have been working on this since the beginning of January. And Andonovska joined me in March…

Time: 19:50

[Students and teacher moving to tables]

Heimdal: On each table there is a little note like this. And on the note there is a context, a room or some things. What I would like you to do is spent a little time, thinking about if you had to create something… if you could develop some ideas. You could draw or you could write… half an hour or how much time you need to develop some ideas.

[During the next 20 minutes, the students and teacher are working and discussing, sitting two by two by each table. There is a lively discussion in the room. Several of them are using their pens to draw and write on the papers, which are placed on the tables]

Time: 41:14

Heimdal: [handing out questionnaire] I just want to ask you very quickly. This is a lot of words. And this is the sample which I would like you to describe [pointing at first sample]. So if you could tick five words you think describe this sample, not this one… but just this one.

Andonovska: I mean they can choose as many as they want… they can choose after that five, only five of the ones, which they think describe the sample best.

[The students and the teacher are filing out their questionnaires]

Time: 45:14

Andonovska: Of the ones, that you have chosen just choose five… Make a circle around.

[The students and teacher continue filling out their questionnaires]

Time: 46:39

Heimdal: You can write anything. There is no word that is forbidden.

Teacher: No word…

Time: 47:35 - end of scene 1

Time: 0:00 – start of scene 2

Heimdal: Are you about to be finished?

Students: Yes

Heimdal: So maybe then when you have finished we would like to just hear very shortly in each table, what ideas you ideas on the context. And then you can also say what you thought about the samples or where you got the ideas from. And what was interesting in the samples and what was less interesting. Just tell me, or tell us, what you thought of the samples and of the workshop [looking at student]. Would you start?

Time: 0:50

Student1: Ehm… we talked a lot about what the problems could be in the… in the mountains.

Teacher: Outdoor equipment for hiking in the mountains.

Student1: Yeah, so first we had to think about what problems there could be. And we talked about cold, and yeah… different temperatures. The tent and bonfire.

Teacher: Then we talked about, you know, solar cells, which you can have on your backpack or your cap, and which can… during the day. And you could use the heat in the tent in the night. For instance if you got wet you could make a hot… heating closet or something in the tent. And then we talked about, if you could print the solar cells on the tent, it would be more flexible and it would give more meaning to… like that.

Time: 2:13

Student2: Yeah then we were talking about we could take the bag and make it smaller…

Student1: Then you could also just do it with the bag without… yeah… the things…

Student2: And that's it. That's the discussion we end up couple of times. Why do it, like that, when you can just do it by hand? It's to add something extra.

Heimdal: Yeah. So you really want. If you add something, you want it to be really in the textile like print the solar cells… patterns and…

Student1: Or maybe these threats should be integrated in the textiles so that the whole shape you can take up and down.

Student2: In my point of view, you can't talk about textiles like that. Because it's add-ons, and I don't think that's textiles. I think it's something you add on to the textile. And it's the textile that really matters in that context. I think it should be more integrated to be fascinating. To be… yeah… more innovative.

Time: 3:18

Andonovska: But I think there is a lot of research in that area. There are making a lot of textiles, that can, kind of do all these mechanical kind of things. Also very tiny little LEDs, that is almost like invisible. It is difficult to work with them, but I think it could be easy to put them on a textile and almost like they are part of it.

Student2: And I know that you have to go through this point before you can go direct to textile, so… that's about it.

Time: 3:53

Heimdal: [pointing at new student at another table] And what about you?

Student3: Yeah we have living room. And we were talking about using the threats as a decoration… We talked about a room divider. If there is one divider. Different things. Where the threats could like open and…

Student4: And the same thing for curtains, where they can open and close and make use the solar cells to like have automatic curtains that opens when the light comes…or the opposite… And then we spoke about like having wallpaper. You use the patterns that you had in there… the light sample. Develop it more, and maybe use different colors. So that you can get new patterns, and make your own patterns…

Student3: And the last thing we talked about was like the button thing could be integrated in the sofa or something. So when you sit down, then light will go on…

Student4: Pretty cool.

Heimdal: And then what did you think about the samples. Like this discussion about how integrated it is in the textiles.

Student3: I think that it should be more integrated in the textiles. It looks like the textile and the technical equipment…

Student4: And I think that maybe the other sample is more interesting…

Heimdal: This one?

Student4: First one. Because that is more about the textile. The movement in the textile. The other one is more just adding a light. And the light could be like… but I think the other one is more interesting in seeing the development.

Time: 6:26

Heimdal: Ok thank you. [pointing at another student]. And what about you?

Student5: We had open office landscape. And talking about stress… and some of the… stress.

Student6: Like a collar, that comes up and divides you from the rest of the room.

Student 5: It could be on the clothes, or it can be on the chair, or something like that.

Student6: Then we had like an ear flower or ear textile thing that could blow up when there is too much noise. And that could be customized for everyone in the country.

Student5: And then we also talked about the thing with the chairs in the window. Maybe cold… or something. And it can change shape when you been sitting down all day and your bottom is soar… something new to sit on. And we talked about… switches… in the room. To make it blank instead of all these wires, so it could be more beautiful in a way.

Student6: Very light and transparent fabrics that didn't take up any space in the room. But could change color and become more or less transparent…

Student5: …Or light maybe?

Student6: Yeah. That's it I guess…

Student5: Oh, and we also talked about clothes like the girl from Canada. Something that can change to everyday clothes, but you can also go to a cocktail party later.

Student6: It rolls up, and you have it like a more flashy outfit.

Student5: Yeah yeah whatever.

Time: 9:00

Heimdal: And what did you think about the samples in the way… what did you find interesting? Or less interesting?

Student6: The movement and the flexibility could be fun to work with. But I also think that the technical part should be more integrated. Or totally exposed.

Student5: I also like the light thing. But the light is like in a… Implemented in a shape. Instead of just lights. That could be interesting.

Time: 9:46

Heimdal: Ok, thank you. [pointing at next student]. What about you?

Student7: We had about the hospital for children. So first we talked about having a blanket, where you could… when your… then you could get more or less air into your button. And then we talked about having these two mixed together. So if you had some buttons that you could press on them, and get different light in and out of the window. So when you press the button, then the shape of the window would change. So the light that comes in was different each time and then makes the pattern on the wall… I think that's it.

Heimdal: Ok, and what did you think about the samples?

Time: 10:44

Student8: Kind of the same. About blankets. I like that one.

Heimdal: That one? [pointing]. Yeah.

Student8: The first.

Heimdal: Do you also study textile design?

Student8: Yeah.

Heimdal: Are you all in you bachelor semester, or?

Student8: No, I'm a year younger. Second and third year.

Andonovska: Do you learn anything about wearable computing. Is it part of your study?

Teacher: No…

Andonovska: Nothing like you the example that you gave with…

Teacher: That workshop with Joanna Berzowska in the architect school. But that is like two years ago, so that is past. I mean, it's because it's so difficult to work with that. You get so little out of it in a workshop if you don't have really access to all these computational things. So it's more I think, most of the students know take textiles in two books that tell about the things. It's not that they haven't heard about it. We don't practice it… We have had lessons that tell about this. You did… it was a mockup idea. It was… the textile idea was very important, but then the technical device wasn't that… so it was vision about the things, but not integrated it them.

Time: 12:27

Heimdal: Yeah, because this one here. The shape memory threat. It has been… I mean we made it work yesterday. It has just taken so long time, because so long time to find the supplier. We ordered it in Canada. And they know nothing about textiles because it's used in robots. So they don't know nothing we can ask them. They don't know. But then we had all the delay with the post and everything. But now it's here, and now it's just. This is something I can get to work half a year on… just this one. But it's been really… to make it work.

Student: Good luck.

Heimdal: Thank you. Thank you very much for coming… We hope you got something out of it…**Time: 13:29 - end of scene 2**

21 Appendix H: Pictures from the Survey (26th of May 2009)

Figure 29 - The picture shows Sample 1 & 2

Figure 30 - The paticipant are brainstorming on ideas based on the presented comutational devices and responsive materials