Energy-harvesting & Self-Actuated Textiles for the home:
Designing with New Materials & Technologies

1 Ice-fern, an evolving sculpture inspired by Gecko Textile

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Abstract
This paper presents a design-led investigation into the design of responsive textiles membranes. Introducing a series of design experiments including the Constellation Wallpaper, a dream for eco-conscious wallpaper, and Ice-Fern, a transformable window-sculpture, this paper discusses, within the context of rising sustainable design agendas, the role and influence of new materials and technologies on the conceptualization and making of responsive textiles. Exploring the intersection between textiles, architecture and smart technologies, this on-going research aims to map out new design territories for smart textiles by questioning how they can be implemented within a domestic context to encourage more resilient environments. More specifically investigating the potential of energy-harvesting & self-actuated textiles, the project hopes to highlight new ways for thinking the home as a more permeable, sensitive and interconnected space.

Keywords
Responsive textiles, architecture, smart materials & technologies, home

Introduction
Within the last decade, textiles became true performers of change. 'Stronger', 'faster', 'lighter', 'safer' and 'smarter', as many qualities Mathilda Mc Quaid contributed to reveal through the 'Extreme Textiles' exhibition (Mc Quaid 2005). One of the key innovations in that field has been the emergence of smart textiles. They constitute a specific type of high-performance fabrics – 'specifically engineered to accomplish a particular performance objective'- because of their capacity to respond dynamically to the environment (Addington, Schodek 2005). As any other smart materials, smart textiles are characterized by their ability to

respond to stimulus from the environment by a specific change of behaviour as for instance a colour or shape change. The very specific shape of these materials – that share similar properties with textiles such as the fact to be woven or flexible- make them a distinguishable category within the variety of intelligent material products. The particularly new dimension of these textiles is that they encourage the invisible integration of sensors and actuators into our environment, are extending the limits of where computation can operate, and enabling materials to interact with their surroundings (Coelho, Maes 2007).

New materials and technologies have always suggested new ways of building by pushing the boundaries of what is possible but this is particularly true for textiles today as they emerge as the new drivers of an architectural revolution (Beesley, Hanna 2005). Beyond smart textiles, architects show a general revival of attention for textiles. While they have always been used in tensile structure and within the interiors, textiles concepts such as pleating, weaving, knotting are increasingly used to inform architectural and building practices. These concepts, alongside with the development of high-performance fabrics – that allow textiles to operate at a building scale-, induce new approaches to construction processes.

By extending textiles' competencies and territories of operation, these technological innovations are radically transforming the nature of the textile design discipline, opening new horizons for textiles to take a leading role in redefining our environments. But today, the design's world is also confronted with the necessity to face the consequences of this ability to engineer the world. In light of what we know about climate change, the rampant consumption and waste of natural resources, the disappearance of ecosystems, these consequences are no longer anecdotal. We have to rethink our design culture in term of sustainable futures. Within this context, where smart materials are too often absent, this paper will explore what can be the nature and significance of energy-harvesting and self-actuated textiles. How these intelligent textiles can encourage the design of a more resilient home? What are the conceptual and technological challenges faced when designing sustainable responsive textiles?

2 Textiles, Architecture and Permanence

Within architectural history discourses, textile-based structures are hardly discussed. The fact that textiles are corruptible material, difficult to preserve to time partly explain the omission. However, it can also be understood as the consequence of two fundamental interconnected preconceptions; first that architecture is about permanence, secondly that vernacular buildings are not architecture. Indeed, art history has taught us that architecture 'began when nomadic existence was replaced by a desire for settlement and the requirement of architecture designed to last for generations' (Beesley, Hanna 2005, Glancey 2000). Architecture from Antiquity till the 19th century has been largely built on the idea of defying human temporality by erecting architecture of permanence.

2 Research for architectural textile, 2009, by Aurélie Mossé

However, the very temporal nature of textiles as a building material clearly challenges this notion. This explains why architectural discourses have only recently taken textiles into consideration, notably under the rediscovery of Gottfried Semper's work in the 19th century who was one of the first to claim for textiles as the main agent of architectural form:

> the beginning of building coincides with the beginning of textiles […] It is certain that a kind of crude weaving began with the pen, as a mean of dividing the 'home', the inner life from the outer life, as a formal construct of the spatial idea. It preceded the simple wall from stone or another material (Semper 2004).

Since then, textiles have largely re-entered the architectural discourse but primarily as a metaphor, a structural inspiration rather than a material for space generation (Beesley, Hanna 2005, Garcia 2006, Spuybroek 2008).

However, the desire for lighter flexible surfaces and structures has drawn architecture towards the idea of fabric as a building technology (Ramsgaard Thomsen 2007). The development of the 'curtain wall' at the beginning of the 20th century -the idea of a building façade that does not carry any other load from the building than its own load- has played a major role in this matter, inaugurating the idea of a façade, 'a skin able to support itself as a unified fabric' (Beesley Hanna, 2005). In the last decade, the development of high-performance fabrics -by allowing textiles to operate at a building scale- has been central to this move from the fabric metaphor to reality. Among others, the work of engineer Frei Otto has been pioneered in demonstrating the particular ability of tensile-based textile architecture to handle with tensile forces better than any masonry or compressed-based building techniques.

3 Like a cloud formation, Ice-fern continually shifts

From deployable and convertible surfaces, to the idea of membranes with the ability to change over time, there is only one step that has been made with the development of pneumatic structures, conjointly with the advent of computer-controlled and increasingly sophisticated mechanical actuators (Habermann 2004). A project such as the Convertible Umbrellas for the Courts of the Prophet's Holy Mosque in Medina by Bodo Rasch is a well discussed example of tensile architecture in motion, exploring basic responsive capabilities to address local environment's conditions (solar exposure, wind load).

These development push one step further the understanding of what a flexible building may be: not only transformable and deployable but a dynamic object responding to change in local conditions, which smart technologies now allow to become reality. As illustrated by the iconic Blur Building by Diller & Scofidio, this is of particular interest because for the very first time in its history, the concept of interactivity dissolves the idea of architecture of substance, of permanence by allowing the building to move from an object subject to time to a building process embedding time in its DNA.

3 The nature of self-actuated textiles

Similarly to architecture, materials are often thought in term of substance: the substrate of which things are made and perceived by the senses, whose fundamental characteristic are the volume and the mass. Embedded with a strong philosophical connotation, the term invokes something that exists by itself, permanently, in opposition to what is changing. But, with the emergence of smart technologies, the perception of materials in their relation to time is radically shifting:

> Whereas standard building materials are static in that they are intended to withstand building forces, smart materials are dynamic in that they behave in response to energy fields. This is an important distinction as our normal means of representation in architectural design privileges the static material: the plan, the section and elevation drawings of orthographic projection fix in location and view in the physical components of a building (Addington, Schodek 2005)

Alongside with immediacy, transiency, selectivity, and directness, self-actuation is one of the fundamental characteristics of smarts materials. It reveals the ability of the material to convert energy into motion, whether this motion operate at a visible or invisible scale. While energy-harvesting materials refer to a process of energy-conversion change -as for example the conversion of light into electricity within solar cells-; self-actuated materials refer to a process of property-change (change of colour, shape).

In both cases, the intelligence becomes internal to the material as it takes place at the micro, if not nano-scale. But what truly makes the difference in the apprehension of the material is that, with self-actuated materials, motion takes over image, placing actions at the core of the matter. This shift has necessarily some implications on the way we work and built with such materials. They introduce a change of paradigm from the 'formal' to the 'behavioural' renewing the textile designer's palette

with a set of unexplored dynamic expressions (Ramsgaard Thomsen 2007). Questioning the temporal qualities and the performance's nature of self-actuated textiles – textile presenting self-actuation's properties- becomes then fundamental to understand their potential.

4 Qualifying responsiveness

What should be the nature and significance of this responsiveness within the domestic context? Ideas about the home vary between cultures and periods but at any one time and in any one place, the home has been concerned with comfort. Comfort is a transient notion. 'It is an invention, a cultural artifice. Like cultural ideas – childhood, family, gender- it has a past, and cannot be understood without references' (Rybczynsk 1986). The present research is concerned with the contemporary home, in a Western perspective. Today, our understanding of comfort is more and more driven by a desire for sustainability, which can be define as the ability of an ecosystem to maintain itself into the future. This desire is rising from the realization of the impacts of our ability to engineer the world, which has lead to 'the segregation of nature into a separate space, remote from mankind's everyday life and culture, totally disconnected from our responsibilities and actions' (Manacorda 2009), till the point of questioning the capacity of the Earth to subsist to our current lifestyles.

The position of this on-going research is to argue that the concept of responsiveness, the capacity to respond in real time to its environment- by encouraging interconnectivity, can improve the quality of our relationship with the environment, which may ultimately reacquaint us with the idea of a more sustainable relationship with nature. It is claimed that energy-harvesting and self-actuated textiles, by questioning the notion of architecture of permanence, have an active role to play in this process, the role of a mediator between a static and dynamic world.

However, the question remains how these intelligent textiles can encourage the design of a more sustainable home? Francesco Manacorda suggests 'sharing a synergic plan with nature for the reduction of its remoteness from humanity' (Manacorda 2009). Synergy implies the coordinated action, the cohesion of various elements belonging to a whole in preparation for the realisation of a common objective. Simplifying the words to the extreme, in order to maintain itself in the future: humanity has to re-establish an interconnected relationship with nature. Consequently this means we have to think the home, thus the responsiveness of smart textiles, not simply in terms of interactivity - possibility of exchanging conversations between two systems- but in terms of interconnectivity, where each part of a system interact with and rely on each other in a relationship of interdependency, where each part cannot be regarded without its correlate. In this perspective, the concept of resilience, understood as 'the capacity of a system to absorb disturbance and re-organise while undergoing a change, so as to retain essentially the same function, structure, identity and feedbacks' becomes even more relevant to address the design of responsive textiles underpinned by ecological thinking as it takes into account the adaptive nature of our world. (Hopkins 2009). As such, this research will explore the concept of interconnectivity as a mean of thinking the relationship between textiles' responsiveness and the user, as a tool of interconnecting the self to the environment.

5 Design as a cultural appropriation of technology

Home is a complex construct. Beyond the specific spectrums through which it can be analyzed, the home is first and foremost an artefact revealing of the nature through which ideas are embodied into matter. As a cultural and spatial production, it is shaped by the materials and tools that give it life. As they change, they challenge not only its materiality, its design and production but also profoundly the way it is conceptualized, experienced and thought.

The purpose of this research is to explore how home is changing as smart textiles are infiltrating its sphere as well as to challenge preconceptions about how these technologies can shape our lives. This is explored through practice-based and design-led methodology where design becomes the method through which the research question is posed, developed and concluded, what has been acknowledged by Schoen as reflection in action. It relies on the understanding of design as a double act of making and giving shape to a purpose, where the act of creation becomes the methodical process through which technology can be culturally appropriated. Indeed, if we must admit that 'the evolution of an object is first and foremost conditioned by changes in technology;

equally important is the fact that design is defined as an appropriation process'. If scientists and engineers are the one to develop these technologies, designers are left with the responsibility to determine which ones to enter our homes and which one to keep out. But the question is not only about which one we select and implement but more fundamentally how we adopt them to make them acceptable in our everyday. In other words design becomes a powerful process to 'adopt technology in our culture by accepting its influence as well as influencing it'. (Gagnon cited in De Winter, 2002).

Prospective, the research adopts probing methods, understood as a series of design experiments aiming at developing embodied scenarios for the future that stands somewhere between reality and fiction, what Anthony Dunne calls 'Material Tale' (Dunne 2005). The goal of these tales is to imagine new ways of thinking the home by drawing critical, sometimes ironic but always tangible scenarios while stimulating debate & discussion about how these technologies could take place in our lives. This implies a strong material focus where the production of material evidence becomes central to the project. This approach is informed by the larger research inquiry into how digital technologies change and challenge architectural design practice developed within CITA (Ramsgaard Thomsen, Tamke, 2009) and is articulated around three intertwined levels of material evidence:

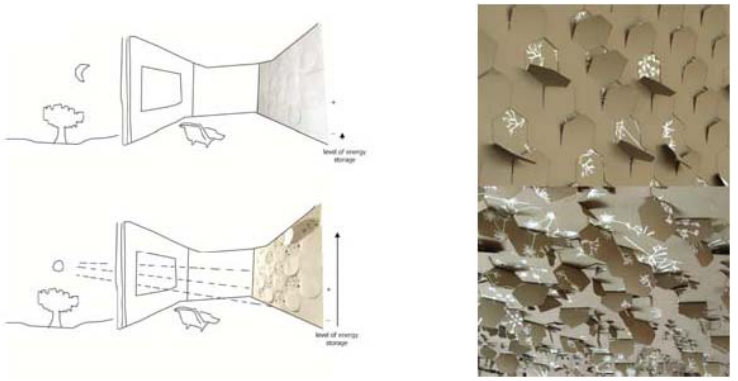
- Conceptual probe: It is a design-led & speculative investigation aiming at developing design concepts and criteria for these technologies. It initially relies on scenario-building and future mapping, developed through sketching, brainstorming and mock-up, eventually leading to the development of a simulation prototype.

- Material probe: exploratory investigation into materials and technologies where the engagement with materials & crafts allow the refinement of the scenarios developed in the conceptual probe.

- Material Tale: embodied scenario materialized by a demonstrator aiming at questioning and mediating our perception of new technology in the everyday.

Aiming at counter-balancing technology-driven research by exploring the cultural, poetical and aesthetical potential of these new materials, the various stages of this iterative process also allow addressing the multiple and inter-disciplinary facets of this investigation. The following presentation illustrates this process through three research artefacts: the Constellation Wallpaper, Ice-Fern and the Photovoltaic Mashrabiya.

6 Constellation Wallpaper: technology as conceptual material for design



4 The Constellation Wallpaper, 2007, scenario building and prototyping

At the origin of this reflexion on how smart textiles can encourage the design of a more sustainable home is the Constellation Wallpaper, inspired by the development of light responsive polymers and inkjet-printed solar technologies. Using design probes methodology, the project investigates the possible role of responsive textiles in future habitats and particularly how smart technologies could enhance sustainability by embedding ecological thinking as core value to address the environmental debate. The Constellation Wallpaper is the conceptualization of interactive wallpaper, where new materials and

technologies are used as a trigger to develop new design scenarios. Touching upon the idea of wallpaper producing and storing electricity into its surface thanks to photovoltaic technologies, it is conceived as double-layered wallpaper with a three-dimensional surface made out of responsive flaps. These flaps open up gradually when the wallpaper is accumulating electricity from the sunlight, revealing a new aesthetic. Marrying laser-cutting and screen-printing techniques with intelligent materials, the Constellation Wallpaper envisions the cross-fertilization of crafts with smart technologies, arguing for the necessity to develop scenarios articulating smart technologies and sustainable concerns. As Anthony Dunne points out, to 'contribute to the production of a habitable world', design needs to be transformed, expanding its scope to include speculation on how best to provide the conditions for inhabitation. It must not just visualize a 'better world' but arouse in the public the desire for one (Dunne 2005).

The Constellation Wallpaper is positioned in this perspective. Exploring the promises of photovoltaic technologies - the only renewable energy susceptible to face our energy needs at a global level'1 (Mau, 2004), the three-dimensional and responsive nature of its surface is used to enhance the visual and emotional qualities of the artefact as a way to promote the compatibility of technological advancements with ecological concerns.

Beyond self-energy sufficiency, the transformation of walls into energy's production place, the project emulates users in becoming producers rather than consumers by creating a situation where it is socially desirable to show that you are an eco-conscious consumer. Encouraging a poetic vision for smart textiles, the Constellation Wallpaper points out the relevance to engage aesthetics in the sustainable debate while also suggesting how technology can become a source of inspiration, a conceptual material for textile designers.

7 Ice-fern: shape-shifting privacy

Ice-fern, a collaborative work by textile designer Aurélie Mossé and architect Mette Ramsgaard Thomsen, is the first probe created within the frame of this research. Halfway between conceptual and material probe, this transformable window-sculpture investigates the potential of shape-shifting textile membranes in the context of modern and post-modern architecture.

5 Ice-fern, 2009, by Aurélie Mossé & Mette Ramsgaard Thomsen

Imagined as a playful structure, Ice-fern addresses the changing anatomy of our living environments. Advocating concepts such as the open plan, the transparency between the inside and the outside, modern architecture has radically transformed the way we understand the relationship between the public and the private. Freeing the façade from any extra load weight, the curtain wall has allowed the expansion of glass, opening 'large window displays' encouraging the staging of everyday life's spectacle to the city. From Mies van der Rohe's famous Lake Shore Drive to Shigeru Ban's Curtain Wall House, this non-structural becoming of the façade has opened the door for textile curtains to enter the realm of architectural language.

Yet, the use of textiles as an environmental mediator between the home and its environment is still under-exploited. Within this context, Ice-fern,

[1] As the sun provides, every two minutes, to the Earth, all the energy we need annually

by pushing the boundaries between curtain and wall, revisits the poetics of the window and how textiles can become an integral part of this ultra-thin architectural space. Inspired by frost formation, Ice-fern is a transformable window geometry evolving over time that can act both as a curtain and a reconfigurable sculpture to filter light and privacy. This faceted-module is designed to be shaped three-dimensionally and playfully drawn from wall to window. It sometimes leaves trace of his presence across the space as it has been programmed to loose some part of its pattern, creating a narrative relationship between the resident and his home that cannot be predicted.

6 Ice-Fern can be shaped and playfully drawn from wall to window

At the core of this artefact resides the use of Gecko textile2, a high-performance and adhesive fabric designed to mimic the sticking power of the Gecko lizard's skin. By allowing the fabric to self-adhere to any glass surface while remaining removable, this silicone-coated textile membrane encourages and reflects in a very tangible manner on the process of inhabitation, which remains, as Hilde Heynen emphasizes: 'an active form of interaction between the inhabitant and its environment in which the individual and his surrounding adjust to each other (Heynen 2005).

Actuation here is not embedded directly within the material: it is the fruit of the interaction between the inhabitant and it surrounding, what we could call a human-actuated textile. But this low-tech interaction suggests an evolving temporality, where the behaviour of the textile is shaped by people desire's to modulate light and privacy in response to environmental factors (presence/absence of light, people). Unlike the Constellation Wallpaper, Ice-fern establishes a mutual dialogue between the inside and the outside in which interconnectivity emerge. This probe can be seen as an initial stage of reflection on the making of responsive textile membranes, allowing by hands-on experiments to explore potential concepts, geometry, aesthetics and function for self-actuated textiles.

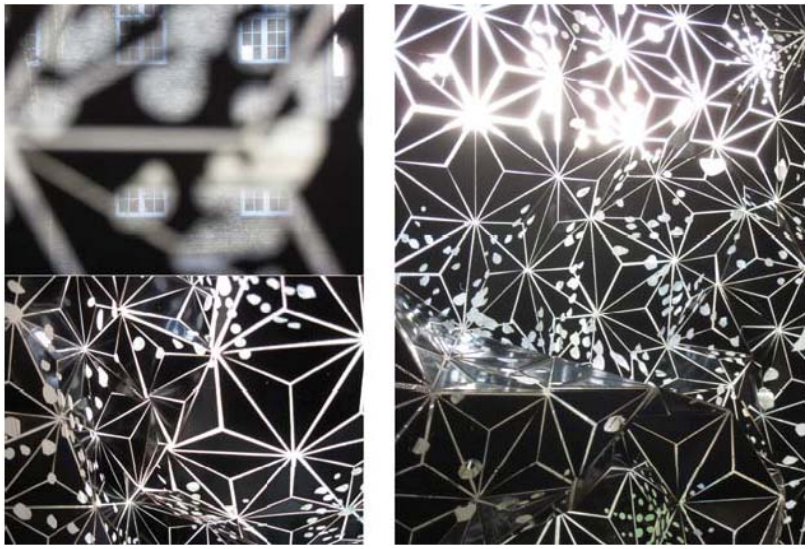
8 Photovoltaic Mashrabiya: 'technology as design material'

What if Ice-fern would become the window itself? What if its performance could be coupled with energy-harvesting & other smart capabilities? The Photovoltaic Mashrabiya is the common denominator for a series of experiments pushing one step further the investigation into shape-shifting textiles by exploring the potential of embedding photovoltaic technologies in its structure.

This soft solar membrane concept, inspired from traditional Arabic architecture seeks to challenge cultural preconceptions about the home, still largely understood as a hermetic shell protecting the individuals from the outside world. This preconception is the inheritance of the Western tradition of holding nature and culture in a 'binary opposition' (Manacorda 2009). This duality, which has enabled us to revere nature from distance, has, at the same time, encouraged the home in becoming an environment primarily conditioned by technology, remote from its surroundings. The design of the Photovoltaic Mashrabiya is an attempt to develop a contemporary vision of Mashrabiya – type of projecting oriel window enclosed with carved wood latticework characteristic of traditional Arabic architecture – by exploring the merging of shape-shifting and energy-harvesting capabilities.

[2] By Création Baumann, http://www.creationbaumann.com

7 Research for photovoltaic patterns, 2009, Aurélie Mossé



8 Photovoltaic Mashrabiya, shape-shifting photovoltaic membrane, simulation

The idea here is not only a membrane converting sunshine into electricity but also changing shape, folding and unfolding to act as a filter adjusting daylight and solar-heating within the interior. The interest here resides in reconsidering the benefits of ancestral architectural strategies to reconcile technology with the idea of home as environmental mediator. Like traditional versions, the Photovoltaic Mashrabiya looks at the permeability between the inside and the outside to regulate privacy, light and air flow without any mean than cleverly managing natural forces. At a second level, this probe also explores the potential of solar cells beyond pure technological performance and functionality by addressing their aesthetical qualities. Exploring technology as a design material, pattern and textiles logic (origami, folding, sandwich – construction technique that combines low-weight with high stiffness and strength – and appliqué techniques - smaller ornament or device applied to another surface techniques -) have been investigated to enhance the visual and haptic qualities of a thin-film solar cell, second generation of photovoltaic technologies whose thinness and flexibility, getting closer to textiles, are characteristic. Textile crafts, usually kept out of the realm of new technology have allowed playing with the current shape constraint of available solar cells to challenge the pervasive aesthetic of the square while preserving the energetic functionality of the material. This has lead to a series of patterns' proposals whose behaviour will be explored with a combination of shape-morphing materials, from shape-memory alloys to bio-actuators, acknowledging the necessity to by pass the need for embedded electronics in the making of responsive fabrics, whose energy consumption does not fit the ecological concerns.

Conclusion

If there is already consequent research into responsive architecture and the development of intelligent fabrics for the build environment, the home remains an under-exploited territory for smart textiles. Moreover, although the idea of responsive environment becomes now tangible through the recent developments in material science and engineering, architects and designers have just started to engage with what smart textiles have to offer. Confronted to the extreme diversity of materials under this label, they are left with the responsibility to decide what are

the relevant materials and technologies that will enable this design of responsiveness and how they will penetrate our everyday.

On one hand, the probes presented here question the nature of this responsiveness. Whereas the Constellation Wallpaper is purely reactive, Ice-fern and the Photovoltaic Mashrabiya suggest that energy-harvesting and self-actuated textiles could promote the design of more resilient habitats by encouraging a relationship of interconnectivity between the home and its environment, thus reacquainting the building in its role of environmental mediator. Beyond the performing, these experiments also investigate the potential of energy-harvesting and self-actuated in terms of poetics and aesthetics, seeking to reconcile the poetic and cultural possibilities of smart textiles with practical and technical ones. This issue is also of high importance in respect to ecological concerns, admitting that aesthetics play a non-negligible role in products' lifespan and consumption. However green they may be, if new technologies fail to appeal to our senses, there is no chance for them to enter how homes on the long term run and we need more designers with high-tech skills to explore these issues.

The intersection between textile, material science and biomimicry represent a particularly promising field of investigation with the development of shape-morphing materials, particularly suitable to face the challenges posed by resilient thinking due to their transformable nature. In that sense, this project will be carried out further through investigation into specific shape-morphing technologies, with a focus on the embedment of electro-active and light responsive polymers into textiles. While the first one present a high amplitude of motion and controlability, the second one, directly actuated by light, represents a huge potential in the attempt to by-pass the needs for electronics in the making of responisve textiles.

From an overall perspective, this paper, by questioning how energy-harvesting and self-actuated textiles can lead to a new understanding of the domestic space and by exploring how they can contribute to the making of responsive textile membranes underpinned with sustainable values, hopes to highlight there is a space for smart textiles to become the actuators of a more sensitive and holistic home.

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