Relational Textiles: surface expressions in space design

The emergence of the Smart Textiles field spurs possibilities for designers to combine traditional surface fabrication techniques with advanced technology in the design process. The purpose of this work is to develop knowledge on interactive knitted textiles as materials for architecture and to do so through practice-based design research. The thesis formulates a research program in order to frame the design explorations, in which scale and material expression are major placeholders. Consequently, Relational Textiles for Space Design is defined as a research program with focus on surface aesthetics and the program is illustrated by design experiments exploring the expressive properties of light, heat, and movement as design materials. As a result of the research presented in this thesis, a new methodological framework for interactive textile design is proposed. This framework defines relational references and frame of reference as basic notions in surface design. These notions form a basis for the method to orient and frame the interactive textile design process. Knitted Light, Touching Loops, Designing with Heat, Textile Glue, Inspection and Textile Visuals in Relation, Enabling the space of Relational Textiles for 3 Space Design, existing surface methodology in architecture, and the new issues that need to be addressed. For which levels of the design process will these textiles be integrated? The last chapter reflects on the role of Relational Textiles for Space Design as possible methods or expressions in the existing space of surface prototyping.
RELATIONAL TEXTILES: SURFACE EXPRESSIONS IN SPACE DESIGN
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Abstract

The emergence of the Smart Textiles field opens possibilities for designers to combine traditional surface fabrication techniques with advanced technology in the design process. The purpose of this work is to develop knowledge on interactive knitted textiles as materials for architecture and to do so through practice-based design research. The thesis formulates a research program in order to frame the design explorations, in which scale and material expression are major placeholders. Consequently, Relational Textiles for Space Design is defined as a research program with focus on surface aesthetics and the program is illustrated by design experiments exploring the expressiveness of light, heat and movement as design materials. As a result of the research presented in this thesis, a new methodological framework for interactive textile design is proposed. The framework defines field of reference and frame of reference as basic notions in surface design. These notions form a basic frame used to revise and present the methods behind the design examples Knitted Light, Touching Loops, Designing with Heat, Tactile Glow, Repetition and Textile Forms in Movement. Relating the space of Relational Textiles for Space Design to existing surface methodology in architecture gives rise to new issues that need to be addressed. For which levels of the design process will these textiles be integrated? The last chapter reflects on the role of Relational Textiles for Space Design as possible methods or expressions in the existing space of surface prototyping.
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A textile architecture: introduction to this research space

The development of construction technology and the aesthetics of form have always been interconnected in the architectural design process because it forms a link between the art of envisioning spaces and the craft of materializing them. For a long time, the conventional view on the art of tectonics in architectural design was that of a hierarchical system in which structure and cover constituted two distinct layers. In terms of surface fabrication, digital tools for representation of objects together with new material fabrication processes have recently opened new possibilities to explore novel spatial expressions based on non-hierarchical geometries in architectural design. Consequently, digital surface fabrication methods in architecture have caused a reframing of the strictly hierarchical principles regulating the design of covers and also initiated a development in which surface design processes in architecture has begun to borrow from the logic of the representation of different non-hierarchical structures such as biological systems and textile construction methodologies.

On a related note, Semper's architectural theory on textiles as a fundamental form of art is reviewed and complemented with new design principles by associating textiles to architecture through the structural representation; new methods combine computational surface design with textile aesthetics (cf. Garcia, 2006). The digitalization of the design process has generated an interest in exploring the structural logics of textile constructions and proposes the use of mixed methodologies in the architectural field. In connection to this, the present fascination with textiles in architectural design originates in the specific way of perceiving surface design for buildings as a non-hierarchical system that allows the designer to play with the depth of the surface design at both the micro and macro levels. A new research paradigm based on experimental design is presently exploring different perspectives on digitalization in relation to the architectural form, e.g. design methods, materials and spatial expressions as well as the relationships between these spaces. Alongside the relationship between these design methods and the structural aesthetics of textiles, there is also a need to articulate the inherent qualities embedded in the physical expressions of the textile materials, e.g. warmth, pliability and tactility, in order to complement the digital qualities.
INTRODUCTION

By exploring different kinds of relationships between digital and physical spaces through textile expressions, the purpose of this thesis is to describe how the characters of the textiles and computation as a design material redefine the notion of space through surface aesthetics, e.g. by merging the digital with the physical, and how spatiality can be questioned through textile and interaction aesthetics. Using a practice-based research methodology, this thesis opens up and explores this design space by relating theory and practice; it questions and discusses concepts of expression and scale in architecture by proposing methods for surface design as well as a language specifically designed to describe textile architectural aesthetics.

The theoretical perspective in this thesis focuses on surface aesthetics and has been developed through design work. Combining physical design with digital tools in material fabrication, the explorations in this thesis center on surface design and use knitting as a construction method. The aim of these explorations is to develop interactive textile surfaces that are able to function as links between the digital and physical spaces of prototyping. The aim of this thesis is to understand the expressive potential of materials through surface fabrication. In the research presented in this thesis, digital prototyping is complemented with a physical textile tool which is developed in order to explore transformational expressions using full-scale samples of the material and to do so beginning with surface construction. Through experimental design, the design examples explore relationships between different interactions in space and the changing expressions of the textile.

The framework proposed by this thesis contributes to the development of surface design methodology and has its background in a new material context in which both textiles and computation as a design material are influential factors. This framework has been derived from a collaborative process that delineates a space formed by textiles, interaction and architecture as these three design perspectives come together in surface design. Thus, the Relational Textiles for Space Design program, which is defined in this thesis, introduces this new material space and illustrates it with methods and expressions based on design variables with specific frames of reference and spatial (field) relationships. The ambition is for the new material space to become a common ground for discussions on methods and aesthetics when combining the three design fields during the surface generative process.
Structure of the thesis

Chapters

The first three chapters form the theoretical foundation of the methodological framework proposed by this thesis. Each of the chapters is structured so as to describe each of the three design perspectives included in this thesis: architectural design, interaction design and textile design.

The first chapter focuses on architectural design and presents the specific research and design context of this field. This chapter also presents an overview of different perspectives on surface design, from digital methods of fabrication to material design. The aim of this chapter is to connect and discuss digital design methods for surface design in architecture, starting with aesthetic theories, materials, design processes and examples of related research. This chapter serves to outline the research work in this thesis and also points to areas that require further exploration through practical work.

The second chapter presents an overview of interaction design methodology with a focus on form and spatiality. The intention of this chapter is to describe how the notion of space is articulated by interaction design aesthetics and, consequently, the chapter comes to focus on major theoretical frameworks in interaction design. The purpose of this chapter is to introduce the aesthetic language specific for this field of design and to summarize notions that will be addressed later on in this thesis.

The third chapter focuses on the description of the textile design process. The chapter provides an overview of the working process of textile structural design and illustrates the different components of the design process: construction, surface and the concept of depth of field, which defines the specificity of the work in terms of structural aesthetics. Because the new textile design space established by this thesis is shaped by smart textiles, this chapter presents this space in connection with the general description of the design process. Also, the concept of computation as a design material is revisited in this chapter in relation to the new design processes for smart textiles and thus reintroduces notions linking the textile expression of transformation to new acts of use from an interaction design perspective.
The fourth chapter describes the practice-based research methodology of this thesis. This chapter explains the context of experimental research in design from a theoretical perspective and provides a background to the presentation of how the structure of the research in this thesis is related to the design work. The fifth chapter describes the Relational Textiles for Space Design research program, which divides the explorations carried out through practical work into two major placeholders: i.e. textile transformable expressions and the scale of interaction. This chapter also provides a short introduction to the research process and the transformable materials explored through practical work such as Knitted Light, Touching Loops, Designing with Heat, Tactile Glow, Repetition and Textile Forms in Movement.

The sixth chapter presents the outcome of the research in this thesis. Although the methodological framework of Relational Textiles for Space Design is a result of analyzing and synthesizing patterns emerging during the practical work with the design examples, the language used in the program traces its roots to the theoretical parts of this thesis. The chapter begins by defining basic concepts that form a foundation for the framework and thus the notions of frame of reference and field of reference are introduced. The framework describes relationships between knitted textile constructions and interaction variables as a method to define spatial expressions when designing Relational Textiles with them. The chapter then goes on to illustrate the methodological framework in practical examples. The examples are revisited in chapter seven, where the concepts presented in the framework are illustrated. The examples are structured according to the materials explored, e.g. light, heat and movement, in relation to different spatial interactions.

The final chapter discusses the results, i.e. compares the design methodology developed in this thesis to related research. The discussion revolves around a perspective that integrates textile aesthetics with architectural design surface methodology and the chapter also presents the main areas suggested for further research explorations by the results of this thesis.

In addition to the above, this thesis also includes seven appended articles.

Papers

List of appended publications


The appended papers have been presented in chronological order as they represent the development of the research work presented in this thesis from both an experimental and theoretical perspective. Although the design examples function as links between the appended papers, there are still different ways in which the practical work presented in the appended
paperns may be interpreted. Therefore, each article supports specific chapters of this thesis and can be classified as belonging to one of the four categories presented below:

i. Context and result oriented (link to chapter 1). Knitted Light: Space and Emotion presents the first design examples created which later came to be part of the research presented in this thesis. This article broadly introduces the design area of this thesis and refers to new methods for surface design in architecture. By reflecting on the role of digitalization as a new aesthetic perspective on material design processes, paper 1 provides a background to the practical work in this thesis by describing current design methods for architectural surfaces. The subsequently developed textile examples are intended as to complement this design space. The perspective in the article on the textile structures of Knitted Light is that they constitute materials for use in architecture and, accordingly, they add new materials to an existing textile construction method, e.g. light transforming sources and computation. The resulting expressions emerge from a design process based on existing technology and methods used to create textile constructions such as industrial knitting and their relationships to new materials, programming and spatial interaction.

The second paper develops the theme of interactive tactility in textiles and further opens up for textiles in the explorations of new design methods. The paper also lays the foundation for the explorations of interactive tactile architectural surfaces that were carried out later. Subsequently, paper 2 introduces and discusses the subject of tactility in architectural space in relation to specific design examples. Thus, the article presents design explorations of knitted structures and tactile interactive patterns. As with Knitted Light, the collection Touching Loops is presented in the form of a new palette of textile materials for architectural design. These materials possess different kinds of abilities that allow them to change their physical structure as a response to direct interaction with the textile surfaces by breaking, shrinking and/or stiffening.

In both papers, focus is placed on the design results in the form of descriptions of selected examples developed through exploration of the new materials, e.g. light and heat. Since this thesis has a practice-based research methodology in which exists a strong synergy between practical and theoretical work, the intension behind the inclusion of these articles in the thesis is to present the initial design explorations as they served to formulate the research program from an experimental perspective.

ii. Research program and design method oriented (link to chapters 1, 2, 3, 4, 5). Paper 3: Interactive textile expressions in architectural design—architecture as a synesthetic expression outlines the design context of this research both from a theoretical perspective and a design perspective. The design program developed through the research presented in this thesis was formulated and motivated in the introduction. This design context brings textiles and architecture together in surface design through the basic criteria used in the design process, e.g. fluidity, structure and the notion of surface as a cover. The research program then adds to these initial criteria the concept of textiles as multisensory materials, which introduces the interaction design perspective. To clarify the details of the research program, the exploratory examples Knitted Light, Touching Loops, Designing with Heat and Tactile Glow are presented to illustrate the proposed design space. Unlike in papers 1 and 2, the design examples are presented from the three different perspectives used in the design process. Thus, each of the three design spaces, i.e. interaction design, textile design and architectural design, bring characteristic variables to be discussed during the design process. In this article, the intersection between different methodologies introduced is presented as a new foundation for discussing the textile design process as a relational method based on associations, e.g. acts of use-material expression, structural design-pattern transformation, spatial interaction as near-field and far-field, temporality.

iii. Research methodology and methodological framework oriented (link to chapters 4, 5, 6). As a method of developing a new methodology specifically for architectural design, paper 4 reflects on the role of practice-based methodologies in this field and discusses the role of material design in this research context. The paper also connects the stages of the explorations carried out in the practical work with the structure of the research methodology proposed in this thesis and its main contribution is that it presents a model of this methodological framework. Compared to the final version found in this thesis, the framework as presented in the article is more of a sketch presented in order to exemplify and illustrate how design methodology can be developed from patterns found in practical work.
Through essential definitions, e.g. frame of reference and field of reference, the article introduces the concept of Relational Textiles for Space Design and explains the notions developed by the framework using Knitted Light as an example.

iv. Design methods, expressions and context oriented (link to the chapter 7). Although in the main text of the thesis the examples have been presented in an overall methodological frame, details regarding the design process found in some of the papers differentiate their content from that of the main text. Thus, papers 5, 6 and 7 present detailed accounts of different textile expressions and collaborative methods developed during the course of this research work, based on the exploration of materials such as heat and movement. These articles describe different design methods emerging from meetings between different design perspectives, e.g. textile design, architectural design, interaction design and fashion design. The three articles are similar in structure, insofar that they present specific textile expressions and the design methods behind them, why they open up for different scenarios of use.

Compared to the way the design examples are presented in the main text of this thesis, i.e. in order to illustrate the methodological framework, the last articles present complete and detailed accounts of the design examples, also presenting all the ideas that emerged during the research exploration. However, some of these directions leave room for further explorations, i.e. work in a given architectural context, on a specific scale or with identity as a body expression.

Paper 5 presents all design experiments involving heat transformable patterns based on knitted constructions. The paper describes the expressions resulting from breaking, shrinking, stiffening, texturizing and warming, alongside with the design methods used to create them. This method developed out of the functions of the design process as a structure to handle meetings between variables from the fields of textile design and interaction design. Therefore, the planning of questions related to surface design questions regarding placement (where), timing (when) and the form of activation (how) all comes down to textile design decisions, e.g. construction and placement of the yarn in the structure. By leaving certain surface variables open, the discussion in this paper transfers these materials to other fields of design such as fashion, product design and architecture and leave room for further reflection on possible integration of them as open textures in those design processes.

In paper 6, a collection of knitted structures capable of motion is presented. It contains different knitted structures designed to be explored in relation to the movement of the motors. Based on the textile designs and the expressions of the motors, the article identifies basic design questions to be asked during the design process: what is the relationship between the knitted pattern and the movement pattern? In what way does the pattern of the motors affect the texture of the surface? How is the direction of movement expressed by the knitted pattern design? The knitted expressions in this article illustrate these answers by describing the emerging patterns in terms of dominance, arrangement and direction in relation to the servomotors. Based on these findings, several interaction scenarios are constructed in the form of contextual interactions. These scenarios are then discussed from a textile perspective, an interaction perspective and a spatial perspective with the aim of establishing a collaborative design language based on the combination of knitted textiles and the expression of motors as a new design material for the architectural space.

Paper 7 takes as its point of departure the experiments with interactive heat patterns and explores movement and body interaction in space by connecting surface transformation to the changeability of the patterns in a dancer’s garments. Similar to the design examples in paper 6, the ones in Repetition have been illustrated by specific expressions and the design method extracted from the design processes. Thus, this article describes the expressions of the pattern translations from the knitted wall to the garments as influenced by the dancer’s movement in space. Based on the form of the pattern translation, terms such as accuracy and distribution were identified and described by the visual changes of the garments. These expressions depended on variables that formed our setting, e.g. walls (knitted pattern, heat pattern, timing and temperature), body movement (timing, shape, recurrence) and garments (shape, print, material). This method and the emerging expressions are viewed in the context of a performance, where a dancer is able to use the setting to create forms of non-verbal communication.
List of publications

Papers


Exhibitions:

2007 Stockholm Furniture Fair, Sweden
2008 Textiles and space, Avantex, Frankfurt, Germany
2008 Stockholm Furniture Fair, Sweden
2008 Textiles and space, Riga National Museum, Latvia
2008 Textiles and space, Furniture Fair, Milan, Italy
2008 Textile Possibilities, Rydal, Sweden
2009 Responsive by Material Sense, Hanover, Berlin, Germany
2009 It is possible, Avantex, Frankfurt, Germany
2012 Patterning by heat, Keller Gallery, School of Architecture and Planning, MIT, Cambridge, MA, USA
2013 Stockholm Furniture Fair, Sweden
2013 Playful Research of Smart Textiles, Archintex, Ronse, Belgium
Image from the exhibition Patterning by Heat, Keller Gallery, School of Architecture and Planning, MIT, Cambridge (MA).
I. On space in architecture

1. Theories

For years, form in architecture has predominantly been discussed as tectonics, i.e. in relation to a physical enclosure where the material and the structure constitute the major elements expressing the art of building (Frampton, 1995). Related to this formal context, the aesthetic concepts of form in architecture have been dominated by the art of construction, i.e. tectonics with focus on the relationship between place, structure and materials. Consequently, classical architectural building ideals have been influenced by these strictly hierarchical systems, which made clear distinctions between structure/envelope, interior/exterior. Framing the concept of tectonics in relation to textile construction systems, Semper describes architecture as having two fundamental dimensions that interrelate in the building craft: the structural framework and the enclosure formed by the elements that fill the hollowness of frame (Semper, 2011). Thus, having placed the focus on the aesthetical envelope, the concept of space as formed by the building enclosure has been overlooked when discussing architectural design. Although space has presently come to be viewed as a fundamental notion in architectural design, it was only later, during the modernist period, that consciousness of space became central to architectural thinking.

The industrial era advanced structural technology and consequently came to support the development of the art of construction. It was in that frame of reference that the synergy between the technological field and the architectural design process allowed architects the possibility to operate new formal expressions based on the relationship between structure and construction. Through the use of innovative materials such as steel and glass, new aesthetical principles were advanced and reflected primarily by the development of structural techniques, but also due to the increased potential of form-making processes brought about by new technology. Thus, the technological progress gradually redefined aesthetical concepts by reframing established concepts, e.g. the precise division between interior-exterior and the strict hierarchy of spaces or volume fragmentation.
Alongside the technical development in the art of construction, the modernist perspective introduced the consciousness of space as a fundamental principle for defining form in architecture and added it to the aesthetics of tectonics, which lead to space being perceived as continuous in relation to the aesthetics of the physical enclosure. Consequently, the concept of space was extended beyond the relationship between tectonic forms and a new time-based principle, the dynamic relationship to the viewer, was articulated. Space became part of the building design process and came to be comprehended as a dynamic entity in relation to its static enclosure, one that related time to relative viewpoints in space (Frampton, 2007). Thus, the static form of the object was related to a temporal dimension and, accordingly, designed to be dynamically experienced. Relating time to the architectural form, Giedion referred to Gropius's Bauhaus building in Dessau as an example of the new possibilities that technology presented the aesthetics of form. He argued that the transparency of the glass façade transformed the relationship to space. As in cubist painting, this property brought multiple fields of perception to the three-dimensional form depending on the observer’s point of view: a "variety of levels of reference, or of points of reference, and simultaneity—the conception of space-time in short" and time became, in this context, the fourth dimension of space (Giedion, 1954, p. 499).

Compared to the modernist form, for which the relationship between space and time relied on the dynamic of the viewer and the continuity of space, the computational age in architecture brought a new perspective on the temporality of space. Time was no longer seen as continuous and linked to a static physical form; instead, it is perceived as programmable, just like any other design material embedded in the physical construction. Accordingly, the notion of time-based space uses dynamics as a fundamental character to redefine the architectural form. Through programming, the architectural form is no longer framed in a fixed envelope or a static frame to be perceived by the viewer; instead, the physical enclosure exhibits a dynamic character of its own, owing to the emergence of new materials and computational tools for surface fabrication. Under the umbrella of temporality, the expression of space is redefined by relationships between both material/immaterial and physical/digital design dimensions.

Reflecting on the digitalization of the design process, Reiser and Umemoto regard the influence of computational methodology to be the establishment of a new design space in architecture; a design space defined by an open system of relationships, unlike the conventional principles of centrality. Thus, contrary to the philosophical and pragmatic views on the Cartesian model as unitarian form, Reiser and Umemoto's model substitutes it by proposing a new concept form: “a material field of ubiquitous difference” (Reiser and Umemoto, 2006, p. 26). Their theory develops a critical framework that outlines a design manual in which the architectural form is defined by relational criteria arrived at through the dichotomy between the unitarian model and the field of forces. Hence, their perspective constitutes a reinterpretation of conventional concepts of geometrical organization, matter and processes. Oosterhuis's perspective emphasizes Reiser and Umemoto's views on form by replacing the concept of field of forces with the flow of data (Oosterhuis, et al., 2002), thus describing architecture from the perspective of the form of change. Inspired by Pask's cybernetic theory (cf. Haque, 2007) on form in architecture, Oosterhuis views form as a connecting network of data. In his view, forms can be reprogrammed according to the user and in this way relate different levels of design rather than describing a stable envelope.

Due to the impact of computation both as a process and as a design material on architecture, the notion of space requires new definitions with regard to the dynamics of form. In this thesis, the existing principles of static form are reassessed by introducing a new perspective on the design of the envelope: form as a dynamic gestalt, complemented by the viewer's interaction in space. Subsequently, the architectural form is dynamically built on the interchange between viewpoints and spatial frames, i.e. shifting between the physical and computational character of the envelope.

Regarding the changes of perspective on the notion of space from dynamic to interactive criteria, Fox and Kemp extends the discussion on form to outline the emergent field of interactive architecture. They describe the concept of interactive architecture as a shift from the mechanical paradigm, which regards changeability of space as a functional asset in building design, to a novel paradigm. Accordingly, they argue that changeability, defined as adaptability related to human interaction in space, ought to be a new criterion describing an organic paradigm. In this context, however, Fox and Kemp's theory (Fox and Kemp, 2009) focuses on discussing the architectural profession and novel tools rather than on the development of specific aesthetic criteria for interactivity in relation to
architectural design. Furthermore, their perspective on interaction includes two fundamental directions, ecology and adaptability, in connection to the needs of the inhabitant overcoming the performance-based technological understanding of the concept of interactive architecture. They argue for interactive architecture as the novel organic paradigm, interrelate concepts similar to biomimicry, and invite further reflections on how adaptability can be related to aesthetics.

However, defining form as dynamic causes the notion of space to become intriguing and also raises demands for new definitions that relate perspectives on materiality and computation to each other. Thus, similar to the way in which the physical enclosure is reinterpreted by dynamic principles based on the combination of new surface design methodology and digital materialization, the concept of space requires specific criteria to be adjusted to the new surface design processes and related to spatial interaction i.e. acts of presence in space.

2. Materials

Unlike the honesty of material use introduced in the architectural design process by modernism (Corbusier, 1986; Kahn, 2003; cf. Kim, 2009), one consequence of the increased technological development is that the current material world is defined by complex typologies. Manzini refers to the novel material context as an expansion of the "world of nameless materials" with unrecognizable identities (Manzini, 1989, p.34): a material world where the surface expression and the complexity of its structure form two distinct layers of design. Accordingly, this novel materiality is no longer characterized by the basic performances and appearances of known materials such as wood, glass or stone. Regarding the technological development, the complexity of the emerging materiality redefines incomprehensible relationships between the structural properties of the material and its surface appearance. Furthermore, embedding such complex design dimensions in the material design makes it difficult for the designer to access all potential expressive levels of the surface design.

The new expressional dimensions added to known materials advance demands on related design fields, such as requiring redefinitions of surface characteristics and uses. Relating the complexity of the emerging materiality to the architectural design process, Mori reflects on the role of the material in architecture as initiating new requirements and relationships for space design. She refers to the need to understand the real design potential of the new materials through experimental research, i.e. exploring fabrication and design methods (Mori, 2002). Consequently, Mori discusses the importance of design and material fabrication as methods to generate new spatial languages, i.e. in order to suggest novel spatial expressions, one has to begin with the design of material properties and proceed all the way to surface construction and appearance.

In addition to these views, Kennedy opens the discussion on the concept of the hollow wall. Her critical perspective examines the indefinite relationship between material appearance and fabrication and the logic behind material use in the architectural design process. By questioning common preconceptions on materiality, she suggests another way of perceiving prefabricated materials. Kennedy links the general cultural perception of industrially produced materials to the way they are employed in the construction of buildings and brings as arguments aspects such as surface properties, associations and cultural values, which she identifies by pointing out the difference between the conventional understanding of the materiality and the changes in values brought about by the advances in manufacturing technology. Depending on the relationship between surface appearance and production, she classifies them either as copycat, cannibal, restless or throwaway (Kennedy, 2001, p.15). By introducing these resonant criteria, her classification aims to provoke reflection concerning the way the natural and the artificial interrelate when defining the material expression and she proposes new methods of use through a set of examples.

Irrespective of the fact that prefabricated materials forward questions on the relationship between the natural and the artificial, the field of smart materials introduces additional values concerning how the surface expression reflects the relationship between its digital and physical characters which require further exploration by designers. Using a basic performance-based description, smart materials are defined as materials possessing dynamic properties, i.e. materials designed to sense and respond (Addington and Schodek, 2005; Ritter, 2007). The concept of smart materials opens a new technological design space and outlines a new material area. This new material area tackles new research paradigms and redefines relationships between the digital and the physical, i.e. between
computational-based processes and material fabrication. As Mori points out, the novelty of the emerging material world is stimulating for research in the architectural field. Consequently, research focusing on material development opens different design perspectives where material forms and computation are linked through various surface design processes.

3. Processes

Currently, material explorations reveal new characters based on computational processes and define related technological or aesthetic languages. Hence, the diversity of available digital processes presents a broad range of methodologies, e.g. from performance-based/instrumental to conceptual-foundational/aesthetic languages, that relate the material world to the digital one. By replacing traditional tools of representation such as physical modeling or perspective drawing with digital tools, the new methods present novel possibilities of conceptualizing the architectural object in a non-physical space. Consequently, the first perspective on the role of digitalization in architectural design was strongly influenced by the research paradigms of the field of computer science (Negroponte, 1975; Mitchell, 1990; Knight, 1994). This research perspective in architecture mainly aimed at developing appropriate tools and the focus of the research was placed on defining appropriate methods for architects to interact with computation when designing. Subsequently, this paradigm came to involve an effort to reduce the physicality of the design process by providing digital tools, which had been developed based on usability and cognition criteria. This research area initiated the development of architectural design tools able to handle the multiplicity of form generation processes that can be expressed by using computational methods.

Following the increased access to computerized technology brought about by ubiquitous computing, the design processes in various artistic fields were faced with new challenges. Since then, the role of digital technology has expanded from a mere “technical imperative to new methods of creative expression” (Negroponte, 1995, p.82). Thus, the advances in the digitalization of the design processes have furthered the development of conceptual frameworks of an aesthetical nature rather than process-based methodologies. Theoretical frameworks began to regard digitalization as an integrative part of the design process and also to reflect on the relationship between the design methods and the emerging expressions. Examples of such theoretical frameworks have been developed by Lynn, Terzidis and Leach and focus on the aesthetics of digital form-making rather than on the techno-functionality of the design process (Lynn, 1999; Terzidis, 2003; Leach, 2002).

Correspondingly, advanced digitalization of design tools has been complemented with a new perspective on the role of the material in relation to the methodology used in building design. Thus, digitalization has come to redefine fundamental relationships between material and forms involving new processes in e.g. fabrication and production. Consequently, the new computational tools have given rise to interest in exploring the connectedness between processes of form generation in architectural design and material fabrication, which has caused an intertwining of physical and digital methods.

Unlike explorations into the aesthetics of tectonics, which have always connected structural and formal elements to a material scale and expression in the design of the physical object (Frampton, 1995), the role of the material in the digital space of prototyping has become structurally neutral, even non-expressive, in relation to surface design. This is contrary to the expressive role of traditional materials such as wood, stone and bricks, which are defined by static criteria and impose specific structural constraints and expressions on the aesthetics of the architectural object. Subsequently, the complete digitalization of the design process brought about a change of focus from the central role of the material expression in the aesthetics of tectonics towards the development of complex methods for surface representation.

In order to emphasize this shift of interest from material to process, Mitchell refers to it as a “provocatively anorexic extreme” in his discussion on materiality and the less significant role of the material expression in the digital space of prototyping (Mitchell, 2009, p.11). His description stresses that the freedom to design form expressions in architecture that computational technology allows is a result of material reduction. Subsequently, material reduction has been considered to be a new design potential, permitting the elaboration of complex surface geometries by drawing the object without having to consider any physical constraints.
Compared to Mitchell’s theory, Liu and Lim’s perspective reassesses the foundational role of tectonic theory and develops an additional way of discussing the aesthetics of construction. Their perspective contributes a new methodological framework that relates digitalization to the existing aesthetic theory of tectonics. By analyzing various construction projects, they look for the way traditional terms such as joint, detail, material, object, structure and construction are redefined by the new, digital tectonics. The investigated terms describe the conventional terminology of tectonics as focused on the aesthetics of the physical structure. Alongside the tectonic terms, the interaction criteria are defined by Frampton as “the correspondence between site and architecture and between people and architecture, using the capacity of topography and perception” (Frampton, 1998). Based on the dual nature of the design process, i.e. both digital and physical, Liu and Lim’s framework complements Frampton’s work with new variables such as motion, information, generation and fabrication to the existing tectonic design criteria, and in doing so, they add new criteria intended to be used when describing the design process itself to the existing tectonic framework: motion, which refers to the use of digital tools in the design process, information, which refers to the integration of interactive systems in the building envelope, generation, which refers to the derivation of form due to the computation of the design process, and fabrication, which refers to the digitalization of the production process of the design (Liu and Lim, 2006).

Research in computer-based form generation processes problematizes the relationship between various methods used to materialize the shape developed in digital space. In relation to this, the freedom of form of the digital model has been discussed by Picon as a crisis of scale of the new architecture. He views the material reduction in the design process and the lack of reference to a physical scale as influences brought about by the expanding dependence on graphical virtual environments along with the detachment from the physical design space (Picon, 2010). Thus, the emerging need to relate the virtual space to reality in the design process raises new questions to be further explored by research in material processes in the field of architecture.
Joining physical materials to digital tools for conceptualization and production raises questions regarding how to relate computation to materiality and how to affect ways of thinking in architectural design. Palz’s research focuses on translating and reforming textile construction techniques such as weaving and knitting using digital processes for form-making (Palz, 2012). His research develops methods somewhere between digital and physical surface prototyping to construct complex geometries inspired by the textile structural logic.

In addition to generative processes for static surface design, the material field outlines new research spaces that combine virtual representations with real ones using various compound methods. A compound materiality represented by dynamic material behaviors challenges the static fundamental criteria and generates paradigms that invites to further investigation in the design process. Thus, explorations of dynamic material forms in the physical space emerge in order to complement explorations in the digital.

Consequently, the dynamics of form related to space interaction through texture or shape transformation becomes a design criterion in many projects. The expression of transition directly embedded in the physical surface design transforms space so that it is no longer seen as a mere static entity, but as a responsive environment. Accordingly, various projects have been developed to explore the relationship between the computational tools used for surface construction and the dynamics of form in physical space. Computational devices embedded in the surface are able to continuously modify shapes and sizes. The surface responds to environmental stimuli, reconfiguring the shape of space (Hoberman). Although the surfaces are not constructed of textiles, the way in which they have been designed uses a textile structural thinking at the architectural scale; the surfaces have e.g. been designed based on a non-hierarchical process generating repetition and continuity.

Similarly, in Implant matrix, Beezley and Elsworthy combine digital modeling and tools for surface fabrication in their design process to create dynamic installations at macro scales. These projects go beyond the digital simulation of structures and materialize the complex geometric design of the surface constructed in the digital environment in physical space. Computational devices embedded in the surface are able to continuously modify shapes and sizes. The surface responds to environmental stimuli, reconfiguring the shape of space (Hoberman). Although the surfaces are not constructed of textiles, the way in which they have been designed uses a textile structural thinking at the architectural scale; the surfaces have e.g. been designed based on a non-hierarchical process generating repetition and continuity.

4. Integrating textile logic: examples of experimental research

Various possibilities have been researched in order to create new surface expressions based on the relationship between programming environments such as Rhino, Grasshopper, Processing and Java and digital fabrication techniques in the physical space such as three-dimensional printing, laser cutting and milling. The fact that these relationships have been studied at different levels of the surface design process account for why different theoretical frameworks present different perspectives on computational design processes and material fabrication. Also, as these frameworks cover an emergent area for which basic research is currently carried out through explorations into material fabrication, design methods, production, functionality and aesthetics, they are founded both on performance-based and aesthetical perspectives.

On a related note, the practice-based research methodology of digital fabrication has gained rise to a broad avenue of research that explores the design of new surface construction methods that combine dynamic modeling with physical representation processes. Ahlquist and Menges design computational design methods to create complex geometries based on programming environments such as Java and Rhino Grasshopper. Borrowing from the behavior of textiles, their methods simulate complex mesh topologies which are then transferred to the physical environment through fabrication. Their design projects develop computational methods for use in form-finding processes that explore the relationships between form, force and material representation. The method developed through their research exemplifies cyclical design alternating between a form-finding process and surface materialization using textile structural techniques (Ahlquist and Menges, 2011).

Also involving textile constructions, Spuybroek extrapolates Semper’s concept of using knots as the fundamental elements in architecture (Semper, 2011). Starting within the material representation, he introduces textile systems to teach students computational methods for surface design. His pedagogical methods connect textile structural techniques to digital representations. Beginning with the textile construction, these methods help students relate textile construction techniques to digital modeling in the process, i.e. they are allowed to explore various surface designs based on textile techniques such as knitting, weaving and braiding (Spuybroek, 2009).
a multiple-scale structure (Beezley and Elsworth, 2006). Although their installation does not use textiles as materials, the depth of detail achieved in the surface expression is connected to a textile process rather than to an architectural design focusing on the far-field perspective. The fragility of the feathery, laser-cut modules corresponds in expression to the fine motions of the structure. Outside the circularity of the design process, between computation and physical representation, another interesting feature of this project is the relationship between interaction and surface expression presented by the project. In Implant matrix, interaction is based on direct activation of the surface, which is emphasized more by the detailed near-field expression of the installation than the far-field one.

Ramsgard Thomsen explores textile logic at various scales using processes including both computational tools and physical representations. The dynamic form of the installation has been decided in the digital space but is implanted in the physical space exploring one of the fundamental characteristics of textiles, e.g. pliability. Her projects Slow Furl and Vivisection explore the relationship between the textile character, structure and movement through the continuous changes in position of the textile membrane. The slow shifts of the textile surface express the dynamics of space. Owing to the softness of the material used, the movement takes on different forms in combination with the surface expression. In this case, the detail of the textile structure does not influence the resulting expressions; the near-field expression is subsidiary to the surface form and movement is used exclusively to support the expression designed for the architectural scale. The dynamic behavior of the created space has a set pattern: the surface is seen as a self-activating organism programmed to follow its own cycles (Ramsgard Thomsen, 2007; 2012).

The projects presented here contextualize the design space of this research. They also present parts of the diversity of research that has been conducted in the field regarding combining textile logic with digitalization in order to design tools and material expressions. The illustration on the right shows this design space and attempts to position the research presented in this thesis compared to the four examples of related research.
II. Interaction design methodology: discussions on form and spatiality

Prior to the computational age in architectural design, space was predominantly discussed in terms of its relation to a physical form. Presently, the character of the emerging digital materiality poses new questions for architectural aesthetics, why the notion of space needs to be reassessed according to the different design perspectives that contribute variables to this novel computational-material context. Interrelating physical and digital variables in the surface design process in order to create dynamic forms and interactive spatial scenarios outlines a new area for space design and, in this context, the dynamics of space relate the design to human presence, which opens the architectural form to interaction aesthetics. Thus, designing interactive forms becomes a twofold process in which notions from architectural aesthetics converge with interaction design methodology. In this case, the concept of relational form brings a perspective to the aesthetics of interaction which it is relevant to discuss in connection to space design.

Therefore, this chapter aims to investigate how the notion of space is articulated by the aesthetics of interaction design and also to examine how different theoretical frameworks discuss spatiality when defining computational artifacts. Here, the presentation deliberately focuses on describing frameworks that focus on form in interaction design rather than on aspects such as usability or cognition. In this chapter, the intention is to describe the way in which the character of computation as a design material redefines the notion of space by merging the digital with the physical and also to describe the way spatiality can be questioned through interaction aesthetics. The purpose is to summarize basic notions in interaction aesthetics and introduce the design language of the field. The notions will be addressed during the formation of the methodological framework developed through the research work presented in this thesis.

There are several views on the interaction design methodology of designing interactive artifacts. To begin with, one of the most influential methodologies places the main emphasis on usability and cognition. For a long time, such frameworks have constructed criteria focusing on the way we interact with artifacts from a functional, experiential perspective why, based on the results of empirical studies, focus in this methodological space has been placed on the user’s perceptions and experiences when interacting with computational technology. Regarding architectural design, this methodological space has had a major impact on the development of digital tools for drawing and conceptualization. Due to the recently expanding interest in combining physical and digital media in the design process, this perspective still makes major contributions to the tools used to develop form-making processes in the field of architecture. When it comes to the aesthetics of the artifact, however, these criteria are restricted to desktop interaction as they are mainly used to design functional tools rather than developing the aesthetics of the artifact.

Introducing the interaction perspective in the development of the architectural design process, Ishi develops material-dynamic structures to support tools for form-finding processes in physical space. Design tools such as Sandscape (Ishi, 2004) and Bosu (Parkes and Ishi, 2010) associate computation with material structures in order to create tangible interfaces. Dynamic physical systems increase the exploration potential of digital modeling by enabling direct interactions with the surface. Systems such as Sandscape and Bosu allow designers to manipulate the object directly and expand the exploration potential of the design object at different scales in the physical space.

Based on the present interest in integrating technology into our daily environments (cf. Borgmann, 1984), the role of computation role has expanded from the desktop paradigm to ubiquitous computing, which has redefined the character of the surrounding spaces (cf. Reikomoto, 2008). In connection with these perspectives, Verbucken discusses the matter of embedding technology in order to create responsive environments as a new turn in design thinking: “These technologies make new interactions possible by providing new sensorial points of contact between our environment and ourselves. In turn, these can allow us to increase our control and understanding of the material environment, and of our creative and productive interaction with it” (Verbucken, 2003, p.54). Accordingly, new methodological frameworks for designing aesthetic interactions have been developed in order to open for different design perspectives on digital technology and, thus, to enrich the language of the field. These frameworks aim to define a specific design language and methods for interaction, i.e. to find appropriate words to describe the character of computational artifacts from an aesthetical perspective.
Correspondingly, Löwgren and Stolterman refer to digital technology as the main material used in forming the dynamic gestalt. They describe digital technology as a material and argue that its main qualities concern communication, which makes it a medium well suited to form temporal and spatial structures.

“Digital artifacts are every bit temporal as they are spatial. In order to perceive the whole, or the dynamic gestalt, of the digital artifact, we need to experience it as a process, which is to say that we need to try it. The gestalt of a digital artifact emerges in the interaction with the user over time.” (Löwgren and Stolterman, 2004, p. 137)

Compared to non-digital artifacts, the nature of the novel material implies new ways of looking at the design process. Consequently, they stress the change from designing a static gestalt to a dynamic one in design thinking. In this context, they complement the concept of physical form by adding time as a design variable, which in turn relates to a process of use. Based on these basic notions, they develop an aesthetical framework that describes use-oriented qualities of digital artifacts starting with major placeholders such as motivation to interact with the artifact, sensations during interaction and social outcomes. Instead of usability criteria, words such as transparency, playability, seductively, pliability, control/autonomy, social action space and personal connectedness are used to provide aesthetical descriptions of expressions connected to interaction with digital artifacts.

Emphasizing the role of computation in relation to the design of physical objects, Hallnäs and Redström lay the foundation of an alternative methodological framework for discussing interaction design (Hallnäs and Redström, 2006). Their perspective underlines the transformation of design thinking away from the conventional way of designing physical artifacts:

1. from what a thing does as we use it to what we do in the acts that define use,
2. from the visual presentation of spatial form to the act presentation of temporal behavior." (Hallnäs and Redström, 2006, p.23)

According to Hallnäs and Redström, these are two major placeholders that are characteristic to the design of computational artifacts. Thus, their design perspective focuses on the act of defining the expressions of use of the computational object based on its material character. In connection to Löwgren and Stolterman’s discussion on the character of the dynamic gestalt, Hallnäs and Redström reflect further on the role of computation as a design material when defining expressions for digital artifacts. Here, digital technology is considered to be an integrative part in the construction of expressions in interactive objects, similar to any other material. Like all materials, computation lends a certain character to design objects as it defines temporality as the central property. Thus, the expressions inherent in the computational objects rely both on spatial and temporal structures in terms of executing programs and their dependence on other physical structures to achieve materialization (Hallnäs and Redström, 2002). In this frame, the form of interaction is defined as based on the acts of use linked to the expressions embedded in the digital artifacts. Subsequently, the concepts of space and time are interrelated in the design of the computational objects when defining its expressions and, thus, the notion of spatiality introduced by the computational object relies both on a physical and a temporal behavior in relation to acts of use.

In connection to the discussions on the dynamic gestalt in architecture, adding computation to the design of physical objects is in fact defining dynamic spatial expressions based on material character and computation in relation to acts of use, i.e. opening a new context for approaching discussions on the materiality, spatiality and scale of digital objects.

Lim et. al. also propose a conceptual framework for designers based on the notions of space, time and information that describes the form of interaction from a design perspective, considering the qualities of use of the artifact rather than defining usability criteria. They place the concept of space alongside the concept of time and information as one of the crucial elements defining form in interaction design as “it often connects physical and virtual spaces at the same time, and, even within a virtual space is very different from what we do with physical artifacts” (Lim, et. al., 2007, p. 247). Thus, the definition of space in interaction design is not only based on the different connections relating the digital to the physical in the designed object but also perceived as resulting from relationships between time frames within the information elements that express the digital space.

On the other hand, integrating computation as a design material in products and spaces also challenges physical design processes to reflect on existing methodologies, which gives rise questions regarding the connectedness in expression between the physical space and abstract digital spaces when defining form in order to become relevant.
Hence, another way of discussing the form of computational objects, i.e. analyzing the relationship between the physical and the digital, was initiated by Dunne. His critical perspective on the existing aesthetics of electronic artifacts reflects on the coherence in expression and scale conveyed by the relationship between the physical and the digital (Dunne, 2005). Dunne organizes the different kinds of relationships he identifies into four categories of objects: package, fusion, dematerialization and juxtaposition. Package and fusion describe the manner in which technology has been integrated into the physical and the way it redefines the material expression, while dematerialization and juxtaposition are diametrically opposed terms that describe the relationship between the physical and the digital as reflected by the expression of electronic objects. Thus, dematerialization refers to a gradual replacement of the function of the physical by the digital in which the coherence in expression with the physical object is still maintained. Juxtaposition, on the other hand, means that the material and the digital are both part of the physical object but separated in terms of expression, i.e. the expression of one does not relate to that of the other.

Taking this reflection one step further, the notions of dematerialization and juxtaposition can be extrapolated when discussing the character of computational objects from the perspective of the form of interaction. When applying this perspective, one approach that comes to mind involves reflecting on the connection in expression formed by the relationship between the digital and the physical as defined by the designed object and also further considering the implications of these relationships, i.e. package, fusion, dematerialization and juxtaposition, when designing the interaction expression.

Connecting computation to physical design when defining interaction expressions is determined by the way the spatial form of the physical object expresses the digital one while constructing the relationship to the acts of use in space. Therefore, Hallnäs introduces a specific methodological construction to structure the design process when designing interactive artifacts. In this context, spacing is described as a fundamental design dimension alongside the design dimensions connectivity, timing and methodology when defining the interaction expression (Hallnäs, 2011). Here, the notion of spacing does not only concern the relationship between the physical and the virtual but also refers to the spatiality of the object in relation to its space of use, i.e. the space opened around the computational object itself when defining its expression of interaction. In this context, the act of designing introduces more aspects to reflect upon that originate in the way the digital and the physical relate within the object in a spatial perspective, i.e. defining the depth of expression, and the way the expression of the object connects it spatially to interaction, i.e. defining the space around the object.

Compared to architectural design, which defines space in relation to a physical form, interaction design views space as being both physical and digital. Reflecting on the design of non-computational objects as static gestalts, we would conventionally consider the concept of form following function to describe the connectedness in expression between the object and its interaction form when designing. According to this criterion, the physical object is explicitly related to one intentional expression, i.e. it connects the expression of the object to a specific function in the physical design, which would cause the object to express a specific spatiality given its physical variables.

Summing up the different perspectives on form in interaction design presented in this chapter, the common definition underlines the shift in thinking from static to dynamic gestalt, which has introduced temporality as a fundamental property. Consequently, the relationship between the two spaces, i.e. the physical and the digital, is critical when designing interaction expressions. Beginning with Dunne’s critical perspective on the expressions of digital artifacts, the way in which the interaction expression is constructed when designing an object reflects how formal variables, both digital and physical ones, intersect in forming the expression of the object and thus opens up for another way of looking at the interaction form when connecting and disconnecting the function and expression of the object in the design.

At the same time, the relationship between the digital and the physical depends on the expressiveness of the physical material to express the computational behavior because the expressiveness of the physical structure allows various spatial perspectives inherent in the expression of the object to be modified and connected. Consequently, the integration of computation as part of the physical structure of the object poses new questions regarding
III. Textiles

1. Knitting Fundamentals

Semper defines two basic elements that determine the fundamental character of a textile:

- a. binding
- b. the cover

Their formal meaning is universally valid. Contrasts within this meaning (everything enclosing, enveloping, covering appears as a unity, as a collective, everything binding as jointed, as a plurality)” (Semper, 2011, p. 175).

According to Semper’s description, the textile construction and the surface are interrelated: the form (the cover) is derived from a non-hierarchical system based on the repetition of the unit (binding), which relates structure to surface appearance.

Referring to knitting as a textile structural technique, the loop constitutes the elementary unit in the construction. Therefore, knitted structures are described as constituting of loop multiplications and intermeshing (cf. Hatch, 1993). Because the construction system of knitting is based on the accumulation of single units, the surfaces derived can accommodate various three-dimensional shapes. Unlike woven textiles, which historically have been used in a range of applications from body covers to space enclosures, knitting technology has mainly been developed in connection to applications intended to be worn on the body. Thus, in order to be able to follow the shape of the body, the textile logic of knitted constructions has developed into a system capable of handling three-dimensional modeling. One result of this is the creation of twisted yarns that support the pliability of the surface in relation to the structural design. With pliability and elasticity as fundamental surface properties, knitted garments allow the body to move.

Compared to the stability of woven textile surfaces that result from the strict geometry of the structure of weft and warp, knitted structures do not manifest the same structural stability due to the fact that their structures are based on interlacing loops, providing the surface a highly pliable character. Thus, knitted materials are mostly characterized as elastic and
suitable for shapes, which is why knitting is generally used in connection with three-dimensional objects. Knitting construction techniques have also been developed to better facilitate three-dimensional shaping during material fabrication. Based on the interlacing of loops, the dimension of the yarn does not impose restrictions on the scale or form of the designed shape; on the contrary, knitting allows the design of patterns at large scales. Accordingly, knitted surfaces can be made three-dimensional already when constructing the material, which makes knitting an ideal technique for the construction of surfaces at the architectural scale.

The texture of a knitted construction may vary and depending on the structural design and the character of the yarn used, both flat and three-dimensional textures may be obtained. The accumulation of small-scale units, which is the technique used to create knitted constructions, permits both organic and geometrical organizations of the elements of the surface. As a result of this construction technique, the surface of a knitted structure can be made to take on a predominantly textural expression. Similar to the textural qualities of other textile construction techniques, those of the surface of knitted constructions are based on the relationship between its structural design and the character of the yarns used. Accordingly, other pattern expressions can be obtained by using special kinds of yarns and colors. There are two basic typologies of knitted patterns: textural/structural and pictorial/Jacquard. The structural patterns provide the textile surface a subtle textural expression and when designing, emphasis is placed on the relationship between yarn and knitting construction. Sketching is usually done directly on the material. The design of textural patterns is based on a unit repeat combining different basic knitted structures such as purl, tuck, float and transfer in order to form unlimited compositions (Tellier-Loumagne, 2009).

Jacquard patterns emphasize the pictorial expression of the fabric. Using this technique, the sketching process can be done with graphical drawings. The Jacquard method allows knitting with selected needles and decisions on a specific placement of the illustration on the material.
(Buck, 1921). The process of deciding on the placement of the pattern and the arrangement of a repeat in the knitted structure is similar to constructing the design of a printed pattern as a placed or repeated motif. Comparing a knitted textile to a screen-printed one, knitting has each needle performing a specific role in the pattern design construction, both involving the structure and the repeat. The method allows combining colorful pictorial patterns with structural design. Although the Jacquard technique allows some alterations of the knitted structure, they are limited by the capability of the individual machine.

2. Textile structural aesthetics: designing with the depth of field

The present fascination with textiles in architectural design stems from an interest in the specifically textile approach to surface design, i.e. a non-hierarchical one in which the structure and the envelope are merged into a single system. Thus, textile structural thinking allows the designer to play with the depth of the surface design at micro and macro levels, which also means one is free to interrelate various dimensions, from near-field to far-field ones, and also to break the segregation between established relations such as structure/envelope, envelope/ornament, and form/surface. In her description of the textile design process, Albers refers to two fundamental dimensions of the process: the inner structure, i.e. the material constructive structure, and the outer structure, i.e. the surface appearance that is the texture (Albers, 2000). According to this view, the final expression of the textile surface is based on these two dimensions, structure and texture, continuously interplaying in the design process, one defining the form of the other. Thus, when planning a textile structural design, the two dimensions become interlaced in the surface design process. The structural dimension refers to formal decisions taken when designing the form of the textile pattern with a focus on variables, e.g. construction, yarn character, tactility and color. The textural dimension refers to the formal decisions taken when designing the visual organization of the textural forms of the textile, i.e. the way the patterns constructed by the structure are arranged on the surface by variables such as size, shape, color, position and direction.

In a structural technique, the character of yarns and the type of construction are essential. They construct the form of the repeat and define the visual organization of the pattern repeat in the texture. In addition to the visual expression, the tactile character of the textile is another of its assets. Working directly with the construction of the textile surface enables the designer to integrate a tactile language alongside the visual one in the design process. Therefore, textural effects on the surface of a textile are expressed both tactiley and visually by relationships between yarns and structure. Using the same yarns with various techniques, e.g. weaving, knitting or braiding, or using the same structure with different yarns may create different surface expressions.

Each structural textile technique indicates a specific construction method and, therefore, each technique produces a particular set of surface expressions. Associating the process of designing a tapestry to forming in visual arts, Albers argues: “It is art work; and, as in other plastic arts, it demands the most direct – that is, the least impeded – response of material and technique to the hand of the maker, the one who here transforms matter into meaning” (Albers, 1993, p. 66). In this way, Albers’ definition unites the methods and outcome of different artistic processes while her definition at the same time opens for further reflection on the specific characters and properties resulting from the individual variations of media and technique in the construction of the surface expression. Concerning the discussion on the working methods of artists, McFadden reflect on the intentionality behind choices of materials and techniques in the design process in relation to the desired expression:
“Materials and techniques serve the needs of artists as a result of intention and choice, not by happenstance or accident. The making of art is dependent on the series of choices as to how and when to utilize a specific material, and how best to transform a material – to give it form – through specific behaviors and actions.” (McFadden, 2009, p. 9)

Therefore, the design as an intentional object is not only constitutes of a concept but also of a specific material and the methods used to construct expressions. The depth of the textile expression, which is built on the interplay between structure and surface design, open for further associations due to the various dimensions embedded in the textiles. Thus, reflecting on the aesthetics of the visual expression, Ruskin’s description of the techniques used by the impressionist painters relates to the methods used in textile design. Regarding modern painting, Ruskin describes the depth of the surface expression in Modern painters I as “Of Truth of Space”, i.e. what one can see or cannot see in an object as different design dimensions coexist within objects (Ruskin, 2009). Accordingly, he describes the notion of depth of space through the different ways of viewing an object when forming the visual gestalt, from proximity to distance, and uses Turner’s method of painting the sky to exemplify his idea.

“His blue is never laid on in smooth coats, but in breaking, mingling, melting hues, a quarter of an inch, cut off from all the rest of the picture, is still spacious, still infinite and immeasurable in depth. It is the painting of the air, something into which you can see, through the parts which are near to you, into those which are far off; something which has no surface and through which we can plunge far and further, and without stay or end, into the profundity of space.” (Ruskin, 2009, p.12)

By overlaying multiple of layers of colors and hues, the flat surface of the painting opens the depth of the visual field and relates its expression to different positions in space.

Similar to the way the depth of the painted surface is formed by the overlapping layers, the structural character of the medium in textile design allows the designer to play with the depth of field when defining the surface expression. The way the yarns interlace in the structure gradually form the visible layers in the textile surface. Consequently, the textile forms exist both in detail and seen from a distance, defining specific expressions that gradually become perceivable to the viewer depending on her different positions in space. Unlike the depth of detail in nature, where everything is revealed to the eye, what one can see in the detail of a textile work is not random; the same way a painter does, the textile designer influences the structural design and chooses which forms to reveal to the eye through decisions on positions in space. Thus, a textile pattern introduces two perspectives in space: one relative to the scale of its structure and the other relative to its visual organization. The way in which the structure, the yarns and the colors have been organized in the textile defines a specific spatiality for the surface expression. Due to the interlacing of decisions relating structure and texture to each other in the surface design process, the space design of a textile construction can be planned to allow certain expressions to appear critical in a near-field perspective and others in a far-field perspective or in both a near-field and a far-field perspective.

During the design process, the textile designer can define which layers become visible depending on the position of the viewer in space. The detailed forms defined by the textile structure offer infinite layers of depth ranging from a near-field perspective of the construction up to a far-field one, i.e. the form of the overall texture in space.

In addition to the near-field/far-field perspectives of the visual expression, a textile also introduces a rich tactile language. Variables such as yarns, construction and colors are defined in the design process so as to express forms that relate to proximity or distance; the way variables relate to one another defines the depth of the visual or tactile organization of the textile and opens for near-field and far-field expressions. Thus, designing for near-field or far-field forms introduces abstract notions into the textile design process, notions that define a spatial perspective of the intended textile form. Near-field and far-field perspectives refer to the way a designer organizes variables in a form to express the relationship between the form and a specific spatial perspective, i.e. playing with the depth of field by starting in the detail of the textile construction and proceeding to form textural organizations or pictorial patterns. Taking this analysis one step further, whether a viewer perceives the form of a painting/object/texture as near-field or far-field is an individual experience, i.e. a personal interpretation of the intention behind the design.
3. A New Textile Design Space

The field of smart materials introduces new values to be explored further by textile designers. An initial description of smart materials define them as materials with dynamic properties designed to sense and respond (Addington and Schodek, 2005; Ritter, 2007). Tao classifies smart materials into three categories, “passive smart, active smart and very smart materials”, according to the manner in which they respond to human or environmental stimuli (Tao, 2001, p.3). Thus, the “smartness” label is applied to materials with advanced structural compositions or with surface properties enriched by adding computational technology.

In the textile field, the design of smart textiles combines traditional methods of structure fabrication with advanced technology. As the digital domain offers the architectural design process an unlimited number of actions when generating forms, textiles also offer unlimited tools for design explorations. Described by Gale and Kaur as “a world of endless material opportunities”, textiles provide complex design variables to explore surface expressions through construction (Gale and Kaur, 2002, p.3). In addition, the development in the electrical or computerized field together with the availability of new yarns, e.g. conductive yarns, light fibers and shape memory alloys, has opened new possibilities for designers to explore methods of designing textiles and envisioning contexts of use. Novel materials together with computation as a design material add new programmable variables, which in turn broaden the scope of the traditional process of surface design. Quinn writes: “Our world seems polarized around sensory extremes: hard and soft, protection and exposure, intransigence and tactility. As textiles embrace new types of fibers and fulfill new roles, they bridge these polarities better than any other material” (Quinn, 2010, p.5).

His view emphasizes the great potential gained by textile design through the development of technology that combines expressions with the diversity of textile characters.

Smart textiles outline an area of research that connects perspectives from different disciplines in its material design. In the field of architecture, Kennedy and Violich explore textiles and digital technology in order to create sustainable living solutions. Soft House presents an alternative concept of living that combine ideas from architecture, digital technology and sustainability in material research. The project associates inherent textile properties such as softness and flexibility with electronics in its material design (cf. Sauer, 2006). Soft textile partitions are capable of continuously adapting to the dynamics of family life, storing and generating energy (Kennedy and Violich Architecture). The emotional value of light is explored in projects such as Light Sleeper or Walls with Ears by Wingfield. Accordingly, Wingfield designs a dynamic textile language for everyday textile products in order to define new relationships to the inhabited space (Loop). Embedding new technologies in textiles, the textile designer creates new sustainable ideas of use for home related products (cf. Quinn, 2009). In her works, Orth’s design explorations investigate the potential of textiles as interfaces for advanced technology. Textile switches combining handmade textiles with electronics invite the user to initiate direct interaction with the textile in order to effect changes in the lighting. The technological side of the material is hidden under the soft elements of the surface, providing the design a traditional appearance (cf. McQuaid, 2005). In the project Dynamic Double Weave, Orth designs novel ways of expressing information using textiles. Different textile techniques such as printing and weaving are combined with Electro Plaid technology and computation to create dynamic forms in the shape of patterns (cf. Braddock, Clarke and O’Mahony, 2005).

By analyzing ways of mapping the structure of the skin and the potential of the new materials and textile technologies, Berzina’s research develops a methodological framework further explored in different experimental projects (Berzina, 2004). The methods she develops in her experimental work alter design processes and recombine them into a frame that outlines collaborations in textile design between fields such as conceptual art, material science and textiles. Using a practice-based research methodology, Worbin develops methods and techniques for the design of dynamic textiles. Her explorative projects, e.g. Textile Display, Costume and Wall-hanging and Functional Styling, are used to develop practical knowledge concerning the design of dynamic textiles. She integrates novel surface treatments and yarns such as thermochromic pigments, conductive yarns and light fibers with existing textile techniques, e.g. weaving, printing and knitting, in order to explore dynamic textiles through design and to find the work pattern behind them (Worbin, 2010).

It is evident from the design processes that dynamic textiles bring with them the need to consider the essential demands that form the links between materials and techniques. As a consequence, answers are
required to questions concerning how to integrate transformations into the design process as part of surface expressions and how to program the transformations to form surface expressions. These questions pose a challenge to the textile design practice concerning material fabrication.

In cases where smart textiles are used as responsive surfaces, however, design of the dynamic expression constitutes only one part of the material design process. When it comes to relating the dynamic expression of the surface to an interaction context, new parameters have to be included in the design. This has to be done in order to relate the dynamic expression of the material to a context of designed actions, relating the change in the material to an interaction (Hallnäs and Redström, 2006). Thus, design criteria for interactive textile surfaces add to the challenges of material fabrication by stating further demands related to surface interaction. Extending the relationship between function and expression from computational objects to textile design, Hallnäs and Redström define a new research program: Textile Interaction Design (Hallnäs and Redström, 2008). The program proposes a new direction for research in the field of smart textiles and suggests that intrinsic and dynamic characteristics of textiles need to be explored further as ways to relate to the perspective of interaction design. These complex design considerations do not only challenge textile practice but the application contexts of materials as well.

Introducing interactive textiles to form spatial expressions opens for new explorations related to the surface design process. Therefore, it is essential to find answers to the initial questions concerning how to relate this new materiality to the methodologies for space design. Accordingly, we need to search for principles that will allow us to expand on the established, static descriptions of these new textiles and to search for new synergies with space design.
IV. Experimental Research in Design

Regarding the research methodologies utilized in architectural design, Groat and Wang describe the field as a dichotomous framework:

“Perhaps the most common device for framing such a dichotomous model employs the terms quantitative vs. qualitative. At its most basic level, this terminology assumes that quantitative research depends on the manipulation of phenomena that can be measured by numbers; whereas qualitative research depends on nonnumeric evidence, whether verbal (oral or written), experiential (film or notes about people in action), or artifactual (objects, buildings or urban areas).” (Groat and Wang, 2002, p.25)

In referring to the dichotomy of quantitative vs. qualitative, Groat and Wang describe the framework as consisting of two fundamental directions that outline the research methodologies in the field and a research space containing a broad range of theories, the languages of which range from normative to aesthetic.

Allen’s view expands on Groat and Wang’s by adding an emphasis on the importance of experimental work in the development of aesthetic theory and, furthermore, describes architectural design as a material practice. In his perspective on architectural research, the development of new paradigms in the field is a result of design practice. Theoretical frameworks are the results of findings that have come out of the design process, which he argues as a method to advance knowledge of the field. Therefore, he views experimental design as a method to generate theoretical knowledge in architecture (Allen, 2000). Similarly, known examples of theoretical works, e.g. Four Books on Architecture (Palladio, 1965) or Towards a New Architecture (Corbusier, 1986), present programmatic and methodological approaches in architecture as they illustrate fundamental theoretical frameworks founded on practice.

Reflecting on the different typologies of design theory, Galle highlights two major placeholders. He refers to the first as the instrumental theory and describes it as focusing on the development of design methods through design processes. The second type, which he refers to as the foundational theory and attributes with laying the foundation of the practice, analyzes the nature of the design practice and opens it up to a larger perspective.
Although Galle in this way divides the nature of design theory in two, he holds the two theories to be equally important as they interplay in the definition of the results of design research (Galle, 2011). He argues that research in design has to be able to balance both these directions, i.e. combining the precision of the practice with the openness of the theory developed. Consequently, analyzing the basis of the instrumental design theory, theoretical knowledge builds on design examples in the same way science grounds theory on natural phenomena. Accordingly, the development of experimental prototypes as part of the research method is essential. The function of the prototype in research is to express “the language of experience” (Stappers, 2007, p.87).

Jones describes the design activity as the “initiation of change in manmade things” (Jones, 1992, p.6). In this case, the role of the design activity is to continually reframe the existing knowledge and to build new foundations for the practice, whereas the role of research in design is to use words to complement the new knowledge gained through the practical examples. Thus, the prototype in practice-based research goes beyond its value as an object of design and becomes a tool for interpretation.

Although the fundamental role of design research is to develop design aesthetics, the focus of the interpretation of the design process may be different: either on the development of performance-based theories, e.g. normative criteria, tools to design objects, or on the development of a new language and methods to describe design objects. Palz’s PhD thesis is an example of the development of a performance-based theory as he develops tools and methods through practice-based research by analyzing the digital process of fabricating textiles in order to be able to translate these constructions to the physical space at the architectural scale (Palz, 2012). Worbin’s research develops new design methods for textile designers. Based on experiments, her work explores new materials through the design process. The methods and variables she formulates aim to raise the awareness of the ways in which the new materials influence aesthetic decisions in textile design processes (Worbin, 2010). Landin’s research, on the other hand, focuses on developing a new aesthetic language in interaction design and she uses experiments and a logical construction that relates methods and expressions to each other. Thus, her thesis proposes a new vocabulary to discuss the design of interactive products (Landin, 2009).

The design process is fundamental in practice-based research as a method of generating new understanding, using the knowledge of the field and continuously adapting it while designing to fulfill the desired vision. Consequently, experimentation and reflection are fundamental tools in practice-based design research. Thus, combining skills and reflections into a method for research helps discover new patterns of work through the design process in which the “unselfconscious process” of developing a new design meets the “selfconscious” process of reflecting while experimenting (cf. Alexander, 1964). Thus, the role of reflection in the design process functions as a “corrective to overlearning” tool that describes the relationship between the making of a design and the decisions taken during the process, i.e. reformulating working ideas that come up as a result of the design process (Schön, 2009, p.61).

In practice-based research, the combination of the designer’s skills in a specific field and his/her experience of the design process constitute an analytical tool that allows him/her to formulate new problems in his/her domain, which may then be explored further. Hence, Jones describes the role of a problem in design thinking as a way to discover new search directions:

“The problem, recognized but not solved, is that of devising languages of design in which the complexity and speed of the designer’s artistic modes of thought can be combined with scientific doubt and rational explanation” (Jones, 1969, p.193).

Referring to the distinction between design as a practice and as a form of research, Friedman suggests that, “It is not the experience, but our interpretation and understanding of experience that leads to knowledge. Knowledge emerges from critical inquiry. Systematic and scientific knowledge arises from the theories that allow us to question and learn from the world around us” (Friedman, 2003, p.521). Thus, formulating the results of design research is to build a coherent model by interpreting one’s own experiments. Combining skills with a critical perspective of the field, the results may suggest a shift in the existing design practice. Regarding changes in research paradigms, Kuhn connects both intuition and experience with the formulation of new scientific theories:

“...though such intuitions depend upon the experience, both anomalous and congruent, gained with the old paradigm, they are not logically or piecemeal linked to particular items of that experience as an interpretation would be. Instead, they gather up to large
portions of that experience and transform them to rather different bundle of experience that will thereafter be linked piecemeal to a new paradigm but not to the old.” (Kuhn, 1977, p. 122)

Moving from natural sciences to design, the act of proposing new results using practice-based research methodology in design connects the construction of the prototype to existing experience, which is learned by practicing existing methods while at the same time exploring a novel idea. The connection between existing methodology and experimenting with a novel idea through design generates a new context for the design object, one which needs to be articulated in words and illustrated by experimental work. Formulating a new program as a working hypothesis, i.e. framing research explorations, is quintessential in practice-based research: the program both enables the formation of an initial foundation for the experimental explorations and initiates a shift in design thinking by introducing a novelty such as a new material, design method or design perspective (Redström, 2011). Thus, the role of the design program is intentional and functions as a working hypothesis for future observations. Although the function of the design program in this research method relates to Popper’s theory regarding the construction of the research hypothesis as a structure for observations, it differs as to the nature of the results: the results in qualitative design research cannot prove or falsify the hypothesis/design program. Instead, the results of design research represent alternatives to existing design situations (Cross, 2007, p.43) and present foundational definitions on which to found new ways of thinking when designing (Hallnäs, 2010). As an example, Alexander’s language of patterns, which was developed during studies of housing and city planning, illustrates a way of presenting design results by defining problems instead of suggesting solutions. He describes the patterns developed as a structure for future designs. The design methods Alexander developed represent alternatives to already existing methods. Thus, he describes the pattern language as a foundation to be enriched by “the countless thousands of other languages” (Alexander, 1977, p.xvi). Simon’s perspective relates to this view and defines design activity as a generative tool for new processes (Simon, 1996, p.163.). This idea emphasizes the purpose of practice-based research in design, which is to continuously build foundations for new knowledge intended to create design.

Regarding the assessment criteria for rigor in practice-based research in design, Biggs discusses three fundamental principles: dissemination, originality and context. Dissemination is the capacity of the results to express clearly the new knowledge extracted from the practical work it has brought to the field. Originality refers to the novelty of the design hypothesis/program proposed to be explored. Finally, context is a critical perspective the work ought to include by positioning itself in relationship to established paradigms (Biggs, 2006). His categorization is driven by the requirements of the Arts and Humanities Research Board on research in arts and design conducted in the UK; the criteria provide both a clear structure to and specifications for practice-based research methodology in arts and design. The precision and accuracy of the theory developed as a result of the experimental process is dependent on a close connection with the design work, i.e. the role of the written text in design research is essential as it provides a theoretical framework which is illustrated by the practical work.

On a related note, Biggs also explains the outcome of research in design as a linking of text and artifacts, i.e. a method to illustrate the new knowledge in the field:

"On the contrary, it is the particular combination of artifacts and words/text that gives efficacy to the communication. Neither artifacts alone nor words/texts would be sufficient. What is required is the combination of the artifact [painting, design, poem, dance, etc.] and the critical exegesis that describes how it advances knowledge, understanding and insight.” (Biggs, 2004, p.7)

Therefore, the examples problematize techniques, expressions and design methods while being designed, whereas the theory as a research result is expressed by the text and illustrated by the designed objects.
V. Relational Textiles: surface expressions in space design

A static textile surface brings into space a single expression built on specific elements such as texture, color and scale. As textural elements for space, design variables such as yarn, pattern and structure merge into a single expression with spatial variables such as scale, shape and use. Consequently, any method intended to form specific spatial expressions needs to allow the initial decisions in textile design to interplay with the spatial appearance. In this context, the textile scale of expression has been known to adjust to the formal space variables. However, if the expression of the textile surface undergoes further development, new questions arise concerning the space design process. The textile changes as we move in space. From an initial expression, new textures are revealed and hidden with our movements, i.e. as patterns interplay with interactions in space. In this case, basic design variables related to the textile scale and expressions need to be redefined in relation to the spatial interaction. Therefore, criteria that define static textile surfaces need to be adjusted in order to answer new questions regarding the changeability of expressions such as: what expressions are displayed by the surface? How do static and transformable layers interrelate in surface design? How do we refer to the textural scale of textiles when we introduce interactive criteria into a space? To which stage in the spatial design process will these textiles belong?

Relational Textiles for Space Design is a research program in design that focuses on surface aesthetics. The research opens up the program to become a framework for explorations in interactive surface design. Through design, the program aims to explore various examples using new textile materials, programming and knitted constructions as surface prototyping methods. In this way, the method combines computation as a design material and textiles to explore various interactive expressions through design. In the design process, the program relates the concreteness of the real-world scale of textiles to the abstract digital space in order to explore the expressiveness of these materials and, in this way, form a complementary view on digital prototyping methods. In this research program, the design explorations attempt to define relationships between the scale and expression of the interactive textile as spatial relations. Thus,
the design examples explore various expressions of textile transformations in relation to spatial interactions as a foundation for describing new surface design methods.

In the design process, relating interaction and transformation in surface design means working with the dynamics of the compositional parameters of the textile surface, relating them continuously to the real-time actions in physical space, as well as modifying the scales of reference of the surface in physical space. In this way, the human scale is considered to be a reference point when defining the surface expression. The human scale is related both to a physical dimension of reference, due to the materiality of the surface, and to a virtual dimension, due to the programmed transformations of the material. In this frame, the static material expression of the surface supports the expressions of transformations, continuously translating them to the human scale as real-time interactions in physical space. The result of defining the scale of reference of the surface as a relation between the transformable textile expression and interactions in physical space is that it appears to be essential to explore two major placeholders in the design process: the textile expression, i.e. the range of transformation expressions of the surface, and the scale of interaction, i.e. the fields of interaction in physical space.

(A) Textile design opens up for multiple fields of interaction in space design by adding to the depth of the near-field perspective, which in turn expands the expressive qualities of the far-field perspective of space. Therefore, the scale of interaction is relatively defined as fields of interaction in space ranging between the near-field perspective of the textile and the far-field one of space design.

(B) Connecting textile design and space design through interaction design creates a relationship between the near-field and far-field perspectives through the expressions of the transformations of the surface. Thus, the transformations express various interaction scales from near-field to far-field.

In order to be able to formulate methods and define expressions for surface design through the design experiments, the research presented in this thesis explores ways of creating relationships between variables from textile design and interaction design that connect various scales of design in space. In this context, surface design is explored as the relationship between the textile expression, given by the static and transformable expressions at different scales in space, and the scale of interaction, i.e. the designed actions in space related to different reference fields in space. Subsequently, the design examples search for ways of exploring and relating the interaction scale and the transformation expression through the textile. On the one hand, this search involves exploring a range of transformation expressions for the textile surface such as tactile and visual and, on the other hand, relating them to various interaction scales in space, from near-field to far-field.

In this thesis, the textile material constituted the object of design and observation. Compared to designing an object that belongs to a specific design space, designing a material involves more than a single discipline. Therefore, carrying out design explorations is an essential part of the integration of a new character such as, in this case, computation into an existing space of textile methods, e.g. knitting. However, to be able to reframe design methods the emerging expressions need to be articulated using a suitable language that opens new directions in the design thinking when referring to the application context, which in this case was surface design methodology for space design. Therefore, this thesis uses a practice-based design research methodology in which theoretical and practical knowledge form a dialogue through experimental research. Accordingly, the research method used to conduct the research presented in this thesis follows the structure of practice-based methodology; for example, the three principles dissemination, originality and context (Biggs, 2006) have been applied in connection to experimental work, which has resulted in the development of a new framework for surface design.

The design program Relational Textiles for Space Design, established by the research presented in this thesis, formulates a common space bordering design perspectives such as those of textile design, interaction design and architecture. As a result, the program proposes major placeholders such as scale and expression to be explored further through experimental work. Therefore, the role of the textile is central for the research process as it connects the three perspectives of textile design, interaction design and architecture and forms a common space that requires exploration through design experiments. As was stated above, the aim of the research presented in this thesis is to explore the expressive potential of interactive knitted structures as materials for architecture. Consequently, this thesis establishes the research program Relational Textiles for Space Design in order to outline...
The role of the design program in this research work was intentional, which means it functioned as a working hypothesis intended to structure the explorations of the experimental work. Accordingly, the program states the aim and the major placeholders of the design explorations. The design program uses the existing theory as a context for the research work and defines a new structure for the practical work, i.e. a way of looking for a pattern of work and stating a specific perspective that is to be used when interpreting the design experiments.

At the same time, the program acts as a link between framing the experimental work and positioning this research in the existing theoretical/design context. Consequently, the theoretical chapter presents and discusses foundational and instrumental theories and presents current research problems in the architectural field concerning perspectives such as those of textile design, interaction design and architectural design. The theoretical foundation together with related examples outline the design space formulated in the program. The aim is to pinpoint methodologies and methods and discuss aesthetical languages related to the research presented in this thesis. The theoretical chapter presents the context of this research work in the form of a critical framework in order to be able to position the current research. Accordingly, the program outlines a new field for interactive textile materials and positions this field as a complement to existing computational methods for dynamic surface design in architecture.

In this thesis, the design process is essential to the explanations of decisions regarding and observations of forms during the explorations. The design process served to develop new knowledge on knitted textile constructions in which new surface design variables complemented interaction and architecture. The results synthesize the knowledge gained through the design process and present one way of interpreting the pattern of work based on the practical work from the point of view of the design program. The results are materialized by a conceptual framework that includes both fundamental and instrumental levels in its presentation of design theory; the framework was developed in the practical work and its foundation was the design program Relational Textiles for Space Design.

The methodological framework is a logical construction based on empirical inquiries, i.e. it relates the design experiments to the theoretical background, which in this context acts as a critical perspective on the practical work. Along with the methodological framework, each of the design examples presented in this thesis have been revisited in order to materialize this foundational structure. In addition to the overall framework, each of the design examples also illustrates specific methods and the nuances of these secondary methods introduced in each of the examples were influenced by the expressiveness of the material explored, e.g. light, heat and movement, in combination with inherent qualities of textiles such as light transmittance, tactility and pliability.
Light as a design material.

The textile surface builds on the interplay between filled and open areas, why a particular kind of duality is built into the textile character as it both functions as a cover while and has the properties of a bendable object. Thus, the interlacing threads constitute an envelope, the surface of which is formed by both material and immaterial relationships. The high plasticity of textiles combined with their finely pored structure enable light to alter their expressions in infinite ways.

Hence, light as a design material can be filtered and reflected by the textile and together, light and textile express an intricate spatial relationship. Directly exposed to light, the porous structure of the textile can change between different states of solidity in its expression. The texture and intensity of light influence the textile surface by varying the surface character from that of a solid object to the complete transparency of air.

Viewing a textile as a boundary object between the inside and outside captures the natural rhythm of light and exhibits its different expressions, retexturing space. As variable in character as a textile, light provides a natural rhythm of change to a space and influences the dynamics of its textures through variations in daylight and seasons. Direct, reflected light allows the thin textile surface to undergo a dramatic transition into a solid volume. Light filtered through the pores of the textile transforms the surface into a translucent mist. The light makes the textile become transparent by capturing the glossiness of glass. What if presence in space becomes as active as natural light, adding a new rhythm of change to the space through the textile texture? Correspondingly, projects such as Tactile Glow and Knitted Light explore ways in which light together with the influence of the interactions in space negotiates different characters within the textile expression.

Streams of Light: an early prototype from Knitted Light, photo J.Berg
Heat as a design material

Each of the dynamic materials explored in relation to textiles brought a specific aesthetic register and posed new questions to be further elaborated on by the textile designs. Heat as a design material provided more depth to the design of the near-field perspective of the textile and opened for experiments relating visual and tactile interaction patterns to each other. The experiments with heat took common associations often provoked by direct contact with textile surfaces as their points of departure. Expressions such as “warm” materials or the “hand” of the cloth describe tactile characteristics intrinsic to textiles, i.e. expressions defined by direct interaction with the material.

Through the use of conductive threads and heat changing materials, we wanted to expand the common characteristics describing conventional textiles and integrate interactive expressions involving heat in the design. Associations such as “warm” to the hand, which describes low heat conductivity, or the “hand”, which refers to the textural qualities of textiles, are redefined through the use of heat-transformable patterns and computation. Projects such as Touching Loops and Designing with Heat set up different interaction scenarios in order to place these types of textile expressions in the space design context and aim to open for reflection on the introduction of near-field expressions of interaction in space.
Movement as design material

A textile texture creates rhythm in a space as the continuous repetition of its forms structures the visual organization of space. By adding movement as a design variable for a textile, the inherent rhythm of its geometry can be recreated both in space and time and will, subsequently, reform the organization of space.

Presence in space has its own rhythm that can be either organic or structured. Thus, the textile pattern can be reformed and repeated in different structures when adding or following movements in space; its rhythm can imitate the activities in space or become part of a performance involving looped actions. Repetition and Textile Forms in Movements illustrate ways of designing with movement as part of the textile expression. In Repetition, the textile expression is built not by movement embedded in the surface but by movement in a space adjacent to the textile. A dancer moving in loops forms a spatial pattern in a given setting and her movements translate patterns that interconnect garments and space. In Textile Forms in Movements, movement is included directly as a design variable in the textile geometry; the textile interprets the movements in space through changes in its structure. Activities are translated between different spaces, merging rhythms.

Sketching movement in paper structures for Textile Forms in Movement
VI. Framework for designing

Relational Textiles: forming a textile design

Each expression is founded on the textile and interaction perspectives as frames of reference for the surface design, i.e. together they define the spatiality of the material. Thus, introducing the interactive layer into surface design, there is a need to be precise regarding how the variables of the textile and interaction frames connect in a spatial perspective when initiating construction of the textile material. Although the interaction form is based on the static form of the textile, its variables are able to connect or disconnect to the spatial perspective defined by the initial expression of the textile. Therefore, the notions of frame of reference and field of reference are introduced to describe initial design decisions made when forming basic textile expressions:

-frame of reference refers to a conceptual frame that defines a specific design perspective. In this framework, examples of frames of reference are the textile and the interaction design. Other examples can be perspectives such as product design and choreography.

-field of reference refers to a conceptual field that defines a specific spatial perspective for the design. In this framework, the duality between near-field and far-field perspectives, the Cartesian coordinate system or the geographic coordinate system are all examples of fields of reference.

The notion of frame of reference is introduced in order to increase the precision of descriptions of the ways in which design perspectives interplay in the textile design process and aims to provide accurate descriptions of the formal variables specific to each perspective and the way they relate to each other in the surface design. The notion of field of reference is introduced in order to increase the precision of the textile design process when discussing how the formal variables of each design frame define a spatial perspective such as near-field versus far-field and aims to provide accuracy regarding the spatial perspective intended for each frame and the way the frames are defined by the surface design.
When planning a textile design, two types of dimensions are interlaced in the surface design process: the structural dimension, which refers to the formal decisions taken when designing the form of the textile pattern with focus on variables such as construction, yarn character, tactility and color, and the textural dimension, which refer to the formal decisions taken when designing the visual organization of textural forms of textiles, i.e. the way the patterns are built up by the structure and arranged on the surface by variables such as size, shape, color, position and direction. Due to the interlacing of decisions relating structure and texture to each other in the surface design process and with regard to space design, it is possible to plan a textile construction to allow certain expressions to become critical in a near-field perspective (proximity to the surface) while others become critical in a far-field perspective (distance to the surface) or for expressions to become critical in both near-field and far-field perspectives. Thus, while designing a textile material in the form of a relationship to interactions in space, it is essential to plan how the physical design will be related to interaction, i.e. to be clear regarding how the textile and the interaction variables are connected to (disconnected from) spatial perspectives in the construction process and also the way they are defined as near-field or far-field expressions.

A matrix for frame relations will be used to represent how the physical design of the textile construction and the interaction form relate to spatiality in the design process. The matrix illustrates how the frames of reference of the textile design and interaction design connect formal variables concerning spatial perspectives in a given design. The matrix serves to structure primary decisions regarding the static textile form prior to initiating the design of the material expression and defines a method of setting up connections between the textile construction and interaction when planning the textile frame. A design $X$ is connected (disconnected) if the frames of reference of the textile and the interaction of $X$ connect (are disconnected) with respect to a given field of reference.

Here, it is important to note that $X$ refers to the intended design, i.e. to the design as an intentional object of the design process. The matrix functions as a collaborative method for textile design: it serves to structure initial decisions when designing a textile construction in order to express relationships to interactions in space.

### RESULTS

Example of a matrix for frame relations

<table>
<thead>
<tr>
<th></th>
<th>connected</th>
<th>disconnected</th>
</tr>
</thead>
<tbody>
<tr>
<td>near e1</td>
<td>$x$</td>
<td></td>
</tr>
<tr>
<td>far $e_2$</td>
<td>$x$</td>
<td></td>
</tr>
</tbody>
</table>

Example. The matrix for frame relations above describes the design of a textile $X$.

**Design brief.** Design a connected textile expression for near-field interactions.

Regarding expression $e_1$, the intention is to design a textile structure for tactile interactions. The emphasis when designing the textile construction is to express direct interaction through near-field variables, e.g. the soft character of the yarns, the construction and the placement of yarns in the structure, together with the size, form and tactile texture of the patterns. Accordingly, the static expression of the textile is designed to connect to different direct interactions with the surface and to express near-field interactions. The design decisions in the interaction frame also refer to near-field variables, e.g. how to design for touch in relation to surface design variables such as the quality of yarn, pattern size and texture of the area intended to be touched and the area that will react to touch. When designing the textile structure, we describe the expression $e_1$ as connected because of the way the design variables have been shaped to express a specific spatial perspective for the textile and interaction frames with regard to the same field of reference, i.e. the near-field perspective.

**Design brief.** Design a disconnected textile expression for near-field interactions.

Regarding expression $e_2$, the intention is to design a textile structure for which the far-field expression responds to direct near-field interactions. The textile is designed to form far-field expressions and the changes the textile surface will undergo is determined by the way presence is detected and reactions triggered by near-field interactions. The focus of the textile frame is placed on the way the textile structure is designed in order to be capable of exhibiting far-field expressions by reflecting on variables such as types of yarns used to hold the construction together, structural relationships
used to form a three-dimensional construction intended to be viewed from a distance, and visual organization of the three-dimensional patterns in the surface such as arrangements, directions and positions. Whereas the design variables of the textile forms in the textile structure have been set only to form far-field expressions, the planning of near-field interaction variables defining the direct manipulation of the surface is done separately, e.g. how to activate the change, the areas detecting interaction and timing of the interaction. When designing the textile structure, we describe expression e2 as disconnected because of the way design variables are shaped to express different spatial perspectives for the textile and the interaction frames and thus different fields of reference, i.e. near-field for the interaction and far-field for the textile.
VII. Design Examples:

1. Light
2. Heat
3. Movement
1. Tactile Glow

In Tactile Glow, the textile is designed to be a modular, self-supporting structure. The solid expressions of the textile shapes are recombined by light. Therefore, light has been embedded in the textile modules to enable restructuring its geometry and taming its solid expression. The aim of the project is to explore the possibilities of the knitted construction while focusing on design of textiles for the architectural scale rather than the design of intricate near-field expressions in the textile structure. In this project, interaction design enters the stage only after the textile expression has been decided on.
Scenario. An irregular shape forms a space. Although the shape is uneven, its texture is expressed by the gentle geometry of interlacing lines, which are visible from a distance and together, these lines compose an ordered structure. From this perspective, the material used to construct the shape is indeterminable and the fact that it is a textile only becomes obvious as one sees the structure up close.

Intrigued by the character of the material, she touches the surface to ensure her senses are not deceiving her. Although the material is stiff enough to support the shape, its fine, looped texture and warmth to the touch tells her it is a textile. When bending its edges, new expressions become visible on the surface as the pattern and the scale of the space is modified. The radiant light and the dullness of the surface undergo a metamorphosis. A vibrant geometric shape of light emerges in the far-field perspective.

Continuing the bending motion, the near-field interaction, the intricate interplay of lights begins to grow and fills a primary shape. Light changes the solidity of the surface in a sequential way by materializing and diminishing in different areas. The depth of the textural expression relates near-field and far-field expressions by following the organic rhythm of the interactions with the surface.

Simulation of the knitted surface in Tactile Glow
Textile Frame

Construction. The knitted construction has been designed so as to form the shape of the textile during production. Stitch transfers shape the form of the textile by moving from the front needle bed to the rear one and when forming the knitted pattern, the stitch transfers together with the total decrease and increase of stitches combine to form a single direction. Each triangular shape created in this process is divided into four rows of Single Jersey. Less densely spaced lines mark the separation between shapes as these areas of Single Jersey are knitted on every other needle.

The dividing lines mark the location where the source of light will be placed later. These areas are less densely spaced to enable the light to reach a certain degree of intensity when placed under the textile surface. Soft Pemotex yarn and fine polyester monofilament yarn are knit together to form the overall shape. When knitted, the yarns are soft in order to allow accurate stitch transfers without breaking the loops. After knitting, the textile is heat pressed at 100 degrees Celsius in a process causing stiffening and about 40% shrinkage of the textile. From being soft, the textile becomes stiff and similar in appearance to a non-woven textile.

Textural organization. The knitted static texture is designed to display far-field expressions. The texture is organized so as to have a foreground and background. Thus, the surface is divided into triangular, three-dimensional shapes. The shapes are in turn divided into smaller geometric forms that emphasize the different relationships within the structure. The lines of the largest of the triangular shapes form the foreground and the mediating lines form the background.

The transformation pattern is created by embedding light sources in the textile structure. Each shape contains a single source of light. The shapes are connected to one another and can be activated to compose different kinds of geometric patterns which in turn generate far-field expressions. The light design is not integrated in the structural pattern but an addition to the surface design.

The light sources are linear, formed by the addition of electroluminescent wire. The light wire is placed on the edges of the triangles of both the background and the foreground. The transformable texture is formed by two layers of light of different color and intensity. When viewed from the front, the two layers of light visually intersect although they are in fact separated in space; their placement in space aims to emphasize the three-dimensional expression of the structure when light is activated. The layer of light of the foreground is more intense than that of the background in order to enhance the three-dimensional expression of the surface.

From a near-field perspective, the surface allows direct interaction to activate the different shapes of light. From a far-field perspective, the textile expresses the transformations as a random interplay between geometric figures that lighting up and go dark again. In Tactile Glow, only near-field interaction is available, whereas the transformations are designed to occur in a far-field perspective.
Frame Relations

The expression of the static textile surface is designed to display a far-field expression and so are the transformations. The surface does not express interaction directly through its design as it has been limited to near-field interaction. Therefore, in this example we describe the textile frame and the interaction frame as disconnected in fields. The interaction area on the surface is tangent to the transformation area. Bending of the textile shapes instantly initiates a visual transformation of the surface. Depending on how much of the surface is activated, different shapes and patterns gradually appear and disappear, forming layers in the foreground and background.

The patterns of light displayed are determined by which shapes are manipulated and for how long. There are three types of foreground shapes that can be activated: a triangle, a square and a hexagon. A short bending action will activate the foreground layer to display a regular far-field pattern for approximately sixty seconds. Interaction of extended duration, e.g. touching the surface, will gradually activate the background patterns starting from the area where near-field interaction was detected and filling the regular shape from a far-field perspective in approximately eighty seconds. The background pattern, which covers the entire surface, lasts longer than the outer shape of the foreground pattern. The different geometric patterns, i.e. the squares, triangles and hexagons, have been programmed to be activated at different time intervals. This is because the foreground areas are of different sizes and are later on to be filled by the background patterns. The textile can be described as a juxtaposition of pattern fields caused by overlapping static and transformable textures of the far-field expression having been activated by the interaction frame.
2. Knitted Light

In Knitted Light, the textile acts as a filter for activities in the outside space. Noises in the street are captured and translated in patterns of light that change the textile appearance. The knitted interactive structures have been designed to function as a translucent filter and to complement the glass facade. The project is based on the concept of the shifting relationship between the responsive light patterns and the presence of people in the outside space. The transparency of the static textile allows the spaces to connect visually. Presence in space alters the visual changes in the textile and thus expands on the static texture of the surface through interactive light patterns. The pattern transformation manifests when the design detects high voices coming from the street.

The structures in Knitted Light were designed using natural and artificial light as textile design variables. Thus, the relationship between the light source and the knitted construction was essential in order to define various dynamic expressions for the textile. Through shadow projection, the pattern of the textile surface is transferred to space at a larger scale. The dynamics of natural light are connected to the density of the textile structures and alter their shadow projections. The texture of the shadow is dynamic and it gradually changes size with the daylight, which allows various states of change in the intensity of the textural projections in space. Changeable layers of light patterns have been then added in order for new dimensions to complement the static knitted texture, thus extending the initial expression of the textile.
Scenario. A fragile textile mesh separates the inside from the outside. Streams of light protrude through the gentle textile skin and project a porous shadow into the interior space; the intensity of the shadows varies according to the character of the incoming light. The discrete reflections of a few delicate rays of light touch the folds of the texture of the textile. The inside space is very quiet and still and the only variation is when people pass through it from time to time. The outside street brings people together; the dynamics of the outside contrast the stillness of the inside.

A high noise expressing happiness as someone meets a friend or a cheerful conversation between two people passing by modify the textile expression. The gentle reflections of the sun on the folds of the textile become an intense line of light when a sound is heard above the hum of the street. A solid area of light begins to grow, slowly outlining the silhouettes of the chatting friends.

Drops of Light close up perspective of knitted surface, photo J. Berg.
2.1. Drops of Light

Textile Frame

Construction. The textile has two distinct patterns on each side. The surface has been constructed using a ridge pattern technique. Polyester monofilament yarns have been knitted only in the back needle bed due to the transparency of the yarn. Consequently, the right side has a ridge pattern made up of rows of stainless steel yarn. Thus, the two patterns of the textile faces interlace in the surface expression without contrasting each other.

On the wrong side, the stitch transfers in the knitted construction has been planned to create small apertures, placed in the construction so as to form a diagonal grid. The grid of fine holes becomes visible at high levels of light. The surface has a reduced three-dimensional texture. The steel yarns are knitted only on the right side of the textile and form ridges, which are separated from each other in the structure. In this way, each line of steel yarn can be used not only to reflect light but also to conduct an electrical current.

Textural organization. The texture has been planned to display both near-field and far-field expressions. Although the structural design exhibits its depth in the near-field perspective, the yarns have intentionally been selected so as to reduce tactility and facilitate far-field expressions. The geometric organization of the textural expression is rigorous. Fine, horizontal lines of steel organize the right face of the textile while a diagonal grid is visible on the back of the material.

The transformable expression of the surface is based on the relationship between point-shaped sources of light and the initial structural pattern as design variables. The ridge structure in Drops of Light is a grid for conducting electrical currents and thus provides a structure to support the placement of LED lights. The level of conductivity can be controlled independently for each line of the grid, which allows activation of LED lights in various modes throughout the textile and facilitates the composition of several different light patterns. In this example, the initial scale of the knitted pattern can be increased by the light patterns. Light patterns can be programmed to expand both locally and gradually on the surface, which allows various layers of patterns to appear and fade. The light pattern has been composed to form horizontal lines that follow the organization of the ridges of the static structure. The intensity of the light pattern in each line is uniform; gradual effects can be achieved by activating areas of the pattern in sequence.
2.2. Moonlighter

Textile Frame

Construction. In Moonlighter, the surface design combines areas of partial knit and ridge patterns in the knitted construction. During the planning of the textile construction, design decisions were made with the intention of varying the density of the textural pattern in relation to the natural light. The pattern repeat has been designed to provide a diagonal direction for the areas of partial knit in order to achieve the desired texture of the surface. The areas of partial knit have been knitted on every other needle in order for them to be able to expand at the back of the textile. The small dents in the lines of the patterns of partial knit lend an irregular expression to the ridges.

Textural organization. The surface expression has an organic appearance due to the variation in scale of the patterns. Although its texture is three-dimensional due to the volumetric expression of the areas of partial knit, this is also due to the volume of the double bed ridges. The ridges are designed to integrate linear sources of light and to display far-field expressions.

In this example, the three-dimensional knitted pattern is designed to weave a second pattern of light into the initial textile structure. The layer of artificial light in Moonlighter has been inlayed directly in every other ridge of the textile structure. The texture of the light has the same shape as the texture of the textile, although at a larger scale. The light pattern has a set design and its intensity varies according to the sound level in the space around it. The light patterns form large areas on the textile and their gradation depends on the intensity of the light.

Frame relations

In Knitted Light, the surfaces express far-field interactions through design. The relationship between the ways of signaling presence in space as indirect interactions and the visual changes of patterns was essential when defining the surface expression. The use of metal yarns and stiff plastic yarns conceals the tactile surface expression in a near-field perspective.

Far-field surface interactions were planned for the textile structure and the transformations. In Moonlighter, the textile and the interaction together form a connected expression through the textile frame in a far-field perspective. In Drops of Light, the textile and the space
interaction are connected through fields in the far-field expression but disconnected in the near-field expression. In both examples, the layer of interactive light patterns embedded in the textile surface relates to far-field positions in space. The pattern changes are reversible and may be visualized and activated from a distance by indirect interactions with the surface such as sound or movement. The area planned to be part of the interaction and the area on the textile designed to exhibit the transformation overlap in space although they do not intersect on the surface. In Drops of Light, although the rhythm of the interaction is slow, the response of the textile is immediate. However, the pattern emerges gradually as the patterns are activated one at a time at a rapid pace. In Moonlighter, the rhythm of the interaction is quick and the patterns of light respond directly to stimuli by activating a whole area of light.

The surfaces in Knitted Light do not invite to near-field interactions with the static textile but instead open for far-field interaction. In both examples, far-field interaction is the only kind available and the interactive light patterns communicate their transformations to the far-field expression by producing changes in the textile in distinct ways. In Drops of Light, the near-field expression of the textile structure is gradually extended to the far-field through amplification of its initial field using the interaction frame. As a result, the field of textile transformation in Moonlighter is directly connected to the fact that the interaction frame spreads the patterns of light all over the surface.

Picture of the surface in Moonlighter when light is activated in the textile ridges, photo J.Berg
1. Touching Loops

Touching Loops explores interactive tactility as an asset in the design of architectural spaces and the project develops a collection of interactive textiles responding to touch. Interactive tactility is explored both as a tactile and visual change in the surface geometry where the hand of the texture of the textile is reshaped by interaction and presence in space is tracked by the changes in the surface expression.

The texture of the textiles has been designed to amplify tactile expressions of the surface. This enhanced tactility is not only the result of the choice of yarns and the design of three-dimensional knitted patterns, as it would be for a conventional textile design, but also a result of the heat texture, which is an addition to the attributes mentioned initially.

The spatiality of the interaction design in Touching Loops is the same as that of its transformable textile pattern. The textiles are capable of both sensing and transforming and they effect alterations of the structure of the knitted patterns when detecting human touch. Thus, the functions of the textile include both receiving tactile input (sensing touch) and providing tactile output (generating heat and reacting by breaking, stiffening or shrinking). The changes in the knitted patterns irreversibly trace the position of interaction on the surface. Accordingly, the relationship between the way the surface is manipulated through direct interaction and the kind of the resulting structural change was of significant importance during the planning of the design. Three examples illustrate how different textural effects such as breaking, stiffening and shrinking are connected to different tactile interactions.

The expressions of breakage, stiffening and shrinkage reshape the architectural surfaces and describe ways of relating the near-field and far-field expressions through tactile interactions. The expressions form new spatial relationships between the geometry and form of the textile.
Scenario. The textile closely follows the curved shape of the wall. From a distance, the irregular form of the space appears to have been divided by the fine, vertical stripes of knit; the uneven stripes repeat in infinite lines, covering the contours of the wall with a high degree of precision. Flat and texturized areas structure the space by repeating in regular loops and, coming closer to the wall, the changes in the visual texture of the textile can be also experienced directly by touching it with one's fingers. When touched, the striped texture of the space can be described as a combination of tiny triangular shapes and smooth areas. By slowly passing one hand over the surface of the wall, the neat borders between the triangular shapes disperse only to gently reform into a new, dense texture. In the tactile texturized areas, the vertical grid gradually divides and fine, horizontal lines appear and fill the openings between the triangular shapes when touching the textile. From a distance, the regular, vertical arrangement of the texture of the textile gradually begins to reconfigure itself. The distance between the vertical lines in the texture of the wall change progressively as a response to being touched and the regular geometry of the texture of the wall becomes an uncontrolled pattern that stretches out onto the curved space.
Textile Frame

Construction. The textile is knitted in a 40% shrinking yarn (Pemotex) and a low-resistance conductive yarn (silver coated copper). The surface combines areas of Single Jersey and areas of double bed patterns. The conductive yarn has been placed in the front bed of the plain knit areas of the structure. This area functions as a receiver for the tactile input. The position of the conductive yarn is always on the right side of the surface in order for it to be reachable by e.g. a person's fingers. The distances between the conductive threads are considered roughly equal to the width of a fingertip. Changes in the texture only appear in double bed knitted areas. Thus, the conductive yarn is hidden in the back needle bed in the double bed pattern areas, which have been designated output areas.

Textural organization. The textural organization of the static design has been planned with regard to both the near-field and far-field perspective. Concerning the far-field perspective, the pattern of the surface texture is regular and the texture organized in repeats of vertical lines. The linear, repeated pattern is divided into two types of textures. The appearance of one of the types of texture is dense and smooth and the other has a structure distinctly recognizable as the result of the organization of fine, three-dimensional shapes. In a near-field perspective, the flat stripes have been split by fine horizontal lines of conductive threads that divide the areas of heat transformable yarn into regular squares the size of a fingertip. The second type of lines in the repeat have a distinctly tactile texture due to consisting of fine, three-dimensional triangular shapes that hide the conductive thread when the textile is viewed from the right. The transformable pattern has been designed for a near-field perspective and the only areas of it that is visible are those that have been texturized to facilitate tactile interaction. The transformation effect is irreversible and produces shrinkage of the textile structure, why the nature of the surface changes is both visual and tactile. The transformation appears at the structural level of the textile and gradually influences the shape of the three-dimensional, triangular shapes and also modifies the distances between the striped patterns visible from a far-field perspective.

Frame Relations

Structure 1 is able to express patterns of various dimensions. The repeat that form the foundation of the texture of the textile has been organized into two areas: one smooth area equipped with sensing properties and one area with a tactile texture performing the function of actuator. Direct interaction with the surface is detected by the flat areas of the textile and manifested by visual and tactile shrinkage of the patterns, whereby the surface expression is redefined. The size of the texturized pattern generated by the conductive yarn depends on which section of the textile the fingers touched and for how long they stay in contact with the material.

Pattern changes manifest gradually over a time period of ten seconds, i.e. the same amount of time it takes the conductive yarn to reach the temperature necessary to achieve maximum
shrinkage effect. Within the interactive pattern, the position of the textile transformation and the area of surface interaction touch upon each other in places and construct near-field expressions. The change appears ten seconds after touching the surface, i.e. delayed in time compared to the interaction with the surface, and together, the textile transformation and the interaction form a loop. The rhythm of the expression is fragmented in irregular intervals which are determined by the intervals at which people activate it in space.

The near-field expressions of interaction are built up progressively in an irregular time frame and are redefined through accumulation in the texture of the textile as far-field expressions. Due to the interaction frame, the textile reduces the pattern field in a near-field perspective and consequently becomes influenced by the interaction frame as the surface also exhibits a gradual growth in a far-field perspective of the texture of the textile. The far-field perspective of the textile is randomly modified by adding new transformable expressions that originate in the near-field perspective.
1.2. Structure 2

Scenario. Irregularly knitted folds break the clear lines of space. The textile separates the inside from the outside in a tangled way while at the same time negotiating relationships between spaces. From one side, the division is clear as reflected light causes the textile to constrain the view from the other side: presences on the outside should not be allowed to influence the expression of the room on the inside. The texture of the wall is in the foreground. Standing on the other side, one is able to follow the silhouettes of people moving about in the room as their shapes and movements are projected onto the patterned textile background. Together with the activities going on in the room, the round shapes of the knitted textile compose a screen viewable from the outside. If one wants to connect more to the outside, placing one hand on the round patterns will form a new relationship between spaces; one that redefines the near-field and far-field expressions. The looped lines dividing the knitted pattern begin to break. Suddenly, the inside is no longer isolated as the textile instead connects the two spaces. Movement on the outside adds a random rhythm to the inside. The outside gently protrudes through the textile filter and becomes visible from the inside.
Matrix for frame relations for Touching Loops, Structure 2

The transformation appears at the structural level of the textile and influences the texture of the round patterns. The surface changes in both a visual and tactile way as it opens up certain areas of the pattern and modifies the transparency of the far-field pattern. The transformable pattern has been designed for both near-field and far-field expressions and gradually fills the form of the foreground with shapes. The transformation effect is irreversible and produces breakage in the patterns of the textile structure.

Frame Relations

Through direct interaction, Structure 2 is able to change the transparency and tactile texture of its patterns. The patterns act both as sensors and actuators. Direct interactions in the form of fingers touching the surface are detected and manifested as breakage by the texture. The rows of conductive yarn are activated one at a time and the number of activated rows of yarn is determined by how many times the person’s fingers touch the material. These interactions generate variations in the transparency and form of the patterns. The changes in the pattern gradually manifest two seconds after touching the pattern, i.e. the time it takes for the conductive yarn to reach the temperature necessary to achieve maximum breakage in the textile.

The textile and the interaction frame connect fields in their initial expression, \( e_1 \), which have both been designed for near-field interaction. The expressions \( e_2 \) and \( e_3 \) have been designed to relate the textile to the far-field expression while disconnecting it from the near-field expression of the textile structure.

Textile Frame

Construction. The textile is knitted in a melting yarn, a low resistance conductive yarn and a polyester monofilament yarn. The surface has been given a geometric design using a Jacquard technique. The Jacquard pattern has been knitted in a 1X3 Net structure. This type of technique allows increased control of the exact position of the yarns in the pattern. The knitted structure has been planned always to have the melting yarn meet the conductive yarn in the front bed. Therefore, changes in structure appear only for specific areas of the surface, closely following the knitted pattern.

Textural organisation. The textural organization of the static design has been planned for both near-field and far-field expressions. The transformable layer connects both near-field and far-field expressions. To facilitate far-field expressions, the surface geometry has been given a regular pattern through the organization of the texture in repeats of circular forms. The texture is divided into two areas. Thus, the foreground is made of circular shapes that constitute the first area and the second one has been formed by finely knitted rows of yarn that fill the space between the patterns, thus forming the background. In a near-field perspective, the round shapes are of a fine tactile texture consisting of the rows of conductive yarn that divide the geometry of the pattern into two. The flat appearance of the second texture hides the conductive yarn from the face of the textile.

Example of bindings used in the construction of Structure 2

Position of the yarns in the structure

Detail of the surface transformation

Example of bindings used in the construction of Structure 2

Detail of the textile structure

Matrix for frame relations for Touching Loops, Structure 2

Example of bindings used in the construction of Structure 2

Detail of the surface transformation

Example of bindings used in the construction of Structure 2

Detail of the textile structure

Matrix for frame relations for Touching Loops, Structure 2
2. Designing with Heat

The project Designing with Heat continued the explorations of Touching Loops by integrating tactile patterns in the design of architectural spaces. Although conventionally considered a functional property, heat is given an aesthetical value in this example. The design of the textile pattern investigates the synaesthetic relationship between tactility and visuality and the depth of the visual expression of the textile surface is increased by the tactile expression of the heat pattern. In this example, the material adds an interactive layer of “warm” patterns to the static organization of the visual and the tactile texture. A striped or honeycomb pattern of heat could be discovered in the near-field expression of the surface by changing the position of the hand on the textile surface. When touched, the knitted patterns became soft heating elements, amplifying the “warmth” of the temporal expressions of the textile.

the interaction frame. Within the interactive pattern, the position of textile transformations and the surface interaction area coincide with near-field expressions in this construction. Change in the surface occurs instantly when it is touched and mirrors the timing of the surface interaction. As in the first example, the rhythm of the expression is fragmented and the intervals are irregular depending on the rhythm of the interaction in space. Depending on the type of change the textile expression undergoes, the near-field expression of interaction directly influences both the near-field and far-field expressions of the textile by modifying the form of the patterns or by visually connecting spaces through breakage of the textile. Although the rhythm activating the near-field surface is irregular, the form of the transformable pattern remains controlled and surface interaction progressively builds up the far-field expression. In this example, interaction modifies the depth of field of the textile both in the near-field and far-field perspective by dividing pattern areas through breakage in the texture.
Scenario Small dots of knit cover the wall; their fine textures stand out against the white background. The white surface is dull, allowing the shy dots to shine and showing off some parts of their textures. Letting both hands play over the surface of the wall causes the points on the textile to connect and small geometric figures form where the textile has been touched. It takes a while to find the proper shape of the dots and when found, one wants to keep it that way for a long time. A gentle heat pattern adds another layer to the geometric shapes formed by one’s hands; however, it takes longer to discern this pattern.

Simulation of the textile surface in Designing with Heat
Frame Relations

The tactile relationship is expressed through the static design of the surface. Thus, initial design considerations in the textile frame are related to the design of the near-field expression. This is why we describe Designing with Heat as having its textile and interaction frames connected through the decisions taken in the structural design of its near-field expression. The rows of conductive yarns act both as sensors and actuators. By placing a hand on the textile surface, heat is activated in the area around it. Touching the conductive ridges also sets off sequential activation of heating in six different areas that conform to the shape of the hand. The texture of the transformable area of the surface depends on which area has been touched. The heat pattern activated by the hand goes through a predefined transformation process. The far-field expression of the surface is static and the visual expression is expanded by adding interactive tactile dimensions to the near-field expression. From a far-field perspective, the transformation expression is inactive. In a near-field perspective, the transformation expression expands the static expression of the textile structure and connects it to the interactive heat expression of the texture. Therefore, surface interaction has been made near-field only. The area of interaction and surface activation coincide on the surface. The rhythm of the expression has been structured according to the equally spaced intervals planned for the heat activation of each shape. The interaction frame and the transformable expression do not produce any modifications of the far-field expression of the textile; instead, they constantly reorganize the arrangement of tactile patterns in the near-field expression.

Detail of the textile surface

Textile Frame

Construction. The structure combines a ridge pattern with a full rib-knitted one. The surface is knitted in intarsia using four yarn feeders in the repeat in order to be able to separate the areas of conductive yarns during production. The machine has been programmed to knit the conductive yarn only in the front needle bed. The textile background is knitted with three elastic threads of PA/Lycra (78/78 dtex) so as to create a dense structure. The surface is dense and elastic in order to raise the three-dimensional texture above the conductive ridges. Textural organisation. Designing with Heat explores the same range of expressions as Touching Loops by expanding the near-field expressions of the texture with immaterial patterns of heat. The design of the surface expression combines static visual patterns with interactive tactile ones. The heat patterns form an overlay of geometric shapes, using the textile patterns as a structural grid. Depending on how much of the material is touched, some parts of the heat patterns are activated and form a full hexagonal shape after a certain amount of time. Therefore, the patterns link visual and tactile dimensions in a synaesthetic relationship concerning the near-field expression. The geometric organization of the texture is rigorous. The pattern is designed in order to connect with the heat pattern through the expression. The texture of the textile is designed to amplify tactile expression of the surface. Accordingly, enhanced tactility is a result of the choice of yarns and the decision to design three-dimensional knitted patterns roughly the size of human hands.

Examples of bindings used in Designing with Heat

Example of surface interaction in Designing with Heat
1. Repetition

In Repetition, the textile structures developed in Designing with Heat have been placed in a new scenario, one which connects near-field and far-field interactions to each other. This design example explores relationships between body and space as a method of integrating movement in the design of spatial patterns by having body and space exchange tactile and visual information through movement. By sensing and reacting to the proximity of a body, the space is able to leave traces such as visual patterns on the garments in the form of temporal expressions. Interactive walls exhibit structured repetitions of warmth and detect and react to direct interactions with the body. Heat-sensitive garments reveal patterns corresponding to the looped movements of the body in the space. The texture of the space affects the changes in the pattern of the garments. Near-field and far-field interactions are connected as the dancer’s looped movements in space form various patterns.
Scenario. Areas of the concrete wall are hiding under the fragile textile structure. From a distance, horizontal lines form the regular repeat of the texture of the textile. Coming closer, the geometry of its fine lines becomes perceptible; thin, interlacing threads draw an intricate pattern on the knitted surface.

The dancer positions her body so that it comes in contact with the wall; the asymmetric shapes of her garments define her position in relation to it. She improvises repetitive movements following the constraints of her garments. She leans her body against the soft knitted parts of the wall. The wall displays a gentle heat pattern where her body has touched its surface. Patterns become visible on the dancer’s garments as temporal expressions; her looped movements in contact with and away from the wall translate the heat texture of the wall into visible patterns in space. Walls, patterns, body movements and garments all connect and form a loop. The rhythm of space is continuously reshaped, its changing forms tracked by the changes in the texture of the garments. Colors, geometries, repeats and contrasts are continuously reshaping, following the timed structure of the movements.
Frame Relations

For the initial expression e1, the spatiality of the textile and the interaction frames is the same as they are linked via a near-field connection. When the wall detects the proximity of the body, the structure reveals its heat pattern. The transformable pattern is also designed for near-field interactions and activated instantly. Although the knitted lines reach maximum intensity in fifteen seconds, the time until complete activation has been achieved depends on the conductivity of the yarn used. Each heat pattern is connected to a sensor. Depending on where the body came into contact with the wall and the time interval between contacts, variations may occur in the accuracy of the translated pattern form and also concerning the distribution of the pattern repeat on the garments, revealing new far-field formations (Dumitrescu, et al., 2012). The expression e2 is designed for the far-field perspective but is activated by near-field interaction; thus, the field of interaction and the textile frame represent disconnected spatial

Textile Frame

Construction. The structure was designed using an inlay knitting technique. The machine was programmed to knit the conductive yarn only as inlays in the back needle bed while the other yarn feeder knits the polyester yarn as a single Jersey in the front needle bed. The structure is robust and elastic in order to permit the plane structure to stretch over the wall, thus allowing the rows of conductive yarn to form a clear pattern.

Textural organization. The textile has two distinct faces. The depth of the pattern is the near-field texture. The appearance of the right side, which is facing the wall, is plain. On the wrong side, the rows of conductive yarn form a looped pattern. The fine shape of the conductive pattern is only visible in a near-field perspective of the textile. From a far-field perspective, the textural organization consists of horizontal stripes equally spaced in a structured geometry.

The transformation pattern is designed for near-field interaction: the conductive lines emit heat following interaction with the wall. The transformation pattern is reversible as surface changes are limited to tactile expressions. Three rows of the conductive

pattern form the repeat of the heated layer and redefine the textile surface at the tactile level in a near-field perspective.

MOVEMENT

Fragments from design process

Essential variables used in the design of Repetition and the relationships between them

<table>
<thead>
<tr>
<th>Walls</th>
<th>Garments</th>
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<tbody>
<tr>
<td>texture</td>
<td>shape</td>
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<td>pattern</td>
<td>colour</td>
</tr>
<tr>
<td>timing</td>
<td>pattern</td>
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<td>temperature</td>
<td>material</td>
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Matrix for frame relations for Repetition

<table>
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<th>disconnected</th>
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<tr>
<td>near</td>
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</table>
Within the surface design, the placement of the textile transformation area and the interaction area overlap in space but do not coincide on the surface. The way timing is designed is of major significance for the overall design. Three time intervals are combined to form a loop that influences the repeat of the pattern in space: the time it takes for the heat pattern on the wall to reach full activation, the time interval between the moment the body comes in contact with the wall and the moment the pattern has been translated onto the garments, and the amount of time the pattern is displayed in space, when the dancer discontinues contact with the wall. The intervals form a repetitive loop that influences the end expression. All three intervals are combined in the dancer’s movements at a slow pace. The rhythm of the expression is continuous and relies on the presence of a structured frame in a performance. The near-field expression of interaction translates the knitted texture of the wall into different shapes by modifying the field of the textile in space as it is projected onto the garments. Due to the dancer’s looped movements, the newly formed patterns change the depth of the design in the relational expression and redefine the far-field expression. The example is described as an expression of pattern translation due to the change in the depth of field in the expression from near-field to far-field, in which the pattern translates into a non-identical form when activated by the interaction.
2. Textile Forms in Movement

Stretching and three-dimensional shaping are two of the properties that define the pliable character inherent in knitting. The static rhythm of textile geometry can be redesigned and controlled in both space and time when the surface characteristics are combined with programmable motors. By including movement as a design variable for the knitted surface, the pliability of the surface can be redefined in a controlled way.

Textile Forms in Movement explore movement as a variable integrated directly into the design of the textile geometry. In these projects, experiments began by carrying out material explorations aiming to investigate the expressiveness of the combination of knits and servomotors. Motors and computation complemented the design of elastic and stiff knitted structures in search of redefinitions of pliability. Depending on the characteristics of the surface, this method can be used to reform different arrangements of the textile geometry in order to e.g. modify the tension of the surface or reposition patterns in a structured way. In this project, the interaction scenarios were subordinated the material explorations as they were developed in connection to the expressiveness of the material. The textile interprets the organic movements in space by registering changes in its structure. Activities and thoughts are translated between different spaces, thus merging rhythms in the textile geometry.

2.1. Expressing Thoughts

By stretching and releasing the textile, the surface geometry can be reformed according to a certain rhythm; a rhythm that follows our gestures. Gestures follow thoughts. Subsequently, the textile pattern can be distorted and repeated in different structures according to the way the surface has been manipulated and the rhythm can distort or structure space to reflect a thought.
Scenario. The structured folds of the textile form the background of the space and its soft geometry organizes the space in regularly repeating patterns. The textile remains immovable.

Pinching the surface with a swift gesture and, in an isolated area, a movement emerges and begins to grow without an echo. The knitted structure is distorted by some of the movements and then rapidly recovers its initial form.

Stretching the surface as far as it will go with a robust gesture and releasing it after a while causes the movements to grow and spread the change to the entire surface. Layers of distorted patterns restructure the surface and form new arrangements that combine slow and rapid movements in the reshaping of the textile texture. Like the looped movements of a dancer in space, the textile establishes a rhythm of its own when parts of it rotate for a while; then it stops, waiting for another gesture that will once again release its dynamic behavior.
Textural organization. The static pattern has a regular geometric organization designed for near-field and far-field interaction. The texture is organized in a foreground and a background. In the foreground, white shapes form a rectangular matrix, which is redevised by another, diagonally oriented grid. Horizontally, the lines of the matrix have been reinforced by rows of knit in another color. The horizontal stripes dividing the white rectangular areas are knitted in the opposite needle bed, which hides them from the right side of the textile. They form the background and become visible only in a near-field perspective when the textile is stretched.

The transformable pattern is decided by the movement and position of the motors as the pattern follows the regular lines of the knitted texture. The rotation of the motors distorts the stretching surface and the straight lines of the textile. The effect of this surface distortion becomes stronger when underlined by the colored geometric shapes emerging on the right side of the textile when the surface is stretched. Although the static pattern is designed to express far-field expressions, integrating the

Textile Frame

Construction. The design of the textile construction is based on the interplay between an area knitted in Single Jersey alternating between the front and back beds. The textile is constructed so as to have the elasticity of the textile stem from the design of the construction instead of the properties of the yarns.

The knitted pattern is structured in two fields. One is a colored area that has been formed by horizontal stripes of wool, knitted only in the front needle bed, and has a plain knitted structure. The second one is an area knitted in white yarn in the opposite needle bed. Because the construction of the knitted areas has been shifted between the back and front beds, the material curls in small folds that follow the direction of the knitted wales. Thus, the textile becomes elastic when stretched vertically.

The pattern of the areas knitted in white yarn are quite complex; each of them are divided diagonally by yet another area, which has been knitted in the opposite bed. The robust, diagonal geometry is visible due to the continuous transfer of loops between the front needle bed to the back, which divides the rectangular shape of the white area in smaller parts.

Simulations showing different textural organizations of the surface when movement is activated

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<tr>
<td>far</td>
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Matrix for frame relations for Expressing Thoughts
movement of the motors allows the transformable pattern to express variations in field. The variations in the near-field and far-field expressions may result from the speed of the rotation of the motors and the dimensions of the area on the textile surface that is activated.

Frame relations

Surface transformations are caused by direct interaction with the surface. The changes in the surface are activated when stretching the textile. Depending on how far the material is stretched and the amount of time it remains in a stretched state, different patterns are revealed. The surface acts both as a sensor and an actuator.

*pinch*. Pinching the surface produces an immediate effect as it activates a single, randomly selected motor on the surface. The motor rotates 180 degrees and comes back to its initial position. Although the area of interaction and the area of transformation are detached from each other, they still form a connected spatial near-field expression for the textile and the interaction in e1. Interaction with the surface instantly causes a change in the surface expression, however in a separate area. The rhythm of the expression is rapid and fragmented depending on the rhythm of the activation. Activating the surface also causes the far-field expression of the textile to transform. Accordingly, the expressions of distortion modify the depth of the far-field expression of the textile due to the pattern reformation of the texture produced by near-field interactions.

*stretch*. Stretching the textile further produces a large, elongated effect on the textile surface. In this scenario, the movement spreads to the whole of the surface and divides and reshapes the texture of the textile to form new arrangements and to reshape the far-field expression. This surface manipulation extends all the way to the far-field interaction and, thus, the textile and interaction frames connect spatial perspectives in e2. The interaction area is included in the transformation area, i.e. they are interpenetrating. Two layers of movements appear due to surface manipulations: one with a rapid pace and another with a slower pace. The first movement layer, the one with the slow pace, divides the texture into smaller areas: the motors have been synchronized and rotate 180 degrees back and forth in an interval of three minutes when the surface is held in a stretched state for twenty seconds. The pattern of the second layer of
2.2. Reflecting Rhythms

Activities in a space have their own rhythm of change; it is organic, but can be expressed structurally by the textile forms. The textile acts as a boundary between spaces that have been separated, relaying information regarding presence in space and collecting and spreading information through changes in structure.

movement is larger, includes a rapid rotation sequence of ninety degrees in ten seconds, and the layer is activated when the textile remains in a stretched state for thirty seconds. Initially, the layers are divided by the time frame only to be combined later on. The two temporal patterns emerge as a result of interlacing interactions when producing the distortion in space and time of the texture of the textile.
Scenario. The structured geometry of the textile is shaped by the clearly visible lines of knit. The robust shapes of the knit add to the fine texture of the wall that forms the foreground of space. From a distance, the distinction between the textures of the textile forms and the wall is unclear; it seems they are made in the same material. From a closer perspective, however, the difference between the rows of knits and the fine pores of the wall becomes obvious.

A change emerges and begins to grow in the near-field expression: the patterns begin to rotate at a slow pace, forming and reforming the shapes. The change spreads to the far-field expression. The pace of the rhythm picks up towards the end of the textile line.

People are circulating around the textile, their movements asynchronous to the changes in the textile. The rhythms in space and in the textile do not overlap as the textile reflects the activities occurring in the other space. Although the static rhythm of the textile restructures one space, its movements reflect the rhythm of the other.

After a moment of stillness, the textile begins a slow-paced replay of a collocation of the events that have occurred in its space. The structure of the textile forms and reforms in slow loops, restructuring the overall geometry in sequences until the other space imposes its influence on its rhythm once again.
is heat pressed at 100 degrees Celsius, which causes it to shrink by 40% and stiffen, i.e. features similar to those of a non-woven textile. Thereafter, textile is folded along the separation lines and heat pressed again to allow it to maintain its three-dimensional shape.

Textural organisation. The textile module has been designed to form a pattern displaying far-field expressions and the variation of the near-field expression of the knitted structure has been reduced. The shapes have been designed to allow different arrangements of patterns using a single module as a multiplying unit. The design of the surface has a regular geometric organization and it is possible to open and close parts of the pattern. The ways in which the pattern transforms are connected to the expressiveness of the motors. Thus, the textiles have been arranged considering the degree of movement of the motors, which are capable of rotating 180 degrees.

During the design process, different arrangements of the textiles were tested together with the motors. The degree of complexity of the textile pattern design corresponds to the number of modules used and the way the movement reshapes its design. When deciding on
the final expression, we selected the arrangement exhibiting the greatest amount of variation when rotating the pattern. Although the overall pattern of the surface has been designed for far-field expressions, the movement introduces near-field expressions in the surface design by opening and closing various areas. By adding backlight to the surface, the contrast of the surface texture increases and enhances the transformation effect. The transformable pattern is reversible and its design is closely related to the geometry of the static design.

Frame Relations

The surface transformations are activated by indirect interaction. The surface has been placed between two spaces that do not communicate. The textile and interaction frames connect spatial perspectives in the far-field perspective for e2. The interactions in one space are manifested by the far-field transformations of the textile in the other space. The activation and transformation areas are separated in space.

Although the rhythm of the transformation is exhibited in one space, it follows the rhythm of the other. Proximity sensors trigger movements. The transformation gradually grows from one end of the surface and spreads horizontally over the whole surface. The pattern transformation forms a repeat consisting of twelve steps and each pattern is sequentially activated at fifteen-second intervals. The transformation spreads to the whole surface. There are two time intervals for each pattern. A short, fast-paced repeat during the initial phase of the movement, allowing the motors to rotate for five seconds, and a second one starting immediately after the first one has ended. The second movement continues until the whole surface has been activated and is slower-paced, ten seconds, and allows the motors to complete the whole pattern. The transformation of the first pattern typology is gradual. The amount of time required to reach full activation of the pattern depends on the dimensions of the surface. The changes in
DISCUSSION

VIII. Discussion

1. Challenging the depth of field of the textile expression

The results of this thesis propose a complementary view on surface prototyping. For this reason, the research work presented in this thesis aims to illustrate, through the methodological framework, a complementary perspective in which textile construction knowledge and aesthetics form a cluster involving several design disciplines. In this thesis, the shifts of perspective on the material design process are intended to enable connecting different methodologies to each other, i.e. shifting from viewing textiles as designed materials to viewing them as materials for design. In this way, Doordan’s reflection on the role of materials in the design process as elements allowing various disciplinary perspectives and methodologies to meet are related to the way the design process has been used to extract new knowledge and redefine working methods (Doordan, 2003). Similarly to the examples of research in the textile field by e.g. Worbin, Berzina and Orth, the expressive potential of the new textile materials in this thesis is explored through experimental design. The research program Relational Textiles for Space Design introduces and describes a textile context, defining a new space where methodologies from architectural design, interaction design and textile design meet in surface expression.

In this thesis, the research intentionally started out in the material dimension in order to explore relationships between different frames that influence the design process, from knitted structures to spatial interaction scenarios. Through design, the experiments have explored the expressive potential of embedding knitted constructions with different types of transformable materials such as light, heat and movement. The aim has been to enrich the static expressions inherent in the initial physical construction of textiles with additional dynamic layers of patterns and also to connect the surface transformations to interactions in space. Knitting technique has been used as surface fabrication method together with programming, conductive yarns and transformable materials, complemented with new, variable layers of design. The design experiments aimed to reveal new relationships between the critical variables specific to
### DISCUSSION

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<td>b. Moonlighter</td>
<td>far</td>
<td>connected</td>
<td>reorganization</td>
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<td><strong>3. Touching Loops</strong></td>
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<td>b. Structure 2</td>
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<td>reorganization</td>
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<td><strong>4. Designing with Heat</strong></td>
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<td><strong>6. Textile Forms in Movement</strong></td>
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Structure for the design examples explored in this research.
each frame in order for them to be considered in future design processes. These relationships form a new structure, i.e. the matrix of frame relations, and a language to be used during design, i.e. relational textiles, exemplified by the methods related to each of the materials explored such as heat, light and movement.

The design examples illustrate methods and expressions of knitted textile surfaces with interactive properties; they also present the relationships between the different levels of the design process, starting with textile fabrication. Thus, each of the examples is presented from the perspective of the overlap of different design dimensions and shows relationships between knitted construction/transformable expression, textile expression/interaction, surface expression/spatialization. They exemplify steps taken in the design process when forming the initial surface design and propose basic architectural scenarios to reflect upon.

Each of the design examples introduces specific spatial relationships. Thus, the relationships found in the designed examples can be classified in two categories, i.e. either connected or disconnected, according to the overlaps of interaction and textile frames as spatial expressions of the surface. Depending on the ways in which interaction design affects the initial textile design, each of the textiles can be embedded with one or more expressions. Thus, the transformational form in Moonlighter can be described as spread. The initial surface design and the expression of transformation have been designed to overlap spatial perspectives with the interaction frame. In this context, the surface displays a connected expression because the only interactions in space available are far-field ones. Similarly, the transformation form in Designing with Heat can be described as a tactile reorganization. The surface describes a connected expression for which the initial textile expression together with the interaction and transformation have been planned to overlap in the near-field expression and amplify its depth. Concerning Touching Loops, two transformational forms have been embedded in the surface, reduction and addition. The initial expression of the surface is designed for depth both in the near-field and the far-field expression. The surface has a single field intended for near-field tactile interaction but multiple fields for transformations and, thus, the transformational form gradually expands from influencing the near-field expression to the far-field expression of the textile. Depending on the degree of activation of the surface, it communicates the transformation to the far-field expression. Thus, regarding textile expressions, the surface depth defines intermediary fields in space from near-field expressions to far-field ones. In this case, the textiles in Touching Loops have been embedded with both a connected and a disconnected textile expression. Tactile Glow describes juxtaposition as a transformational form as the way its surface transformation is connected to interaction is different from the other examples: interaction always takes place in the near-field and is disconnected in field from the transformational form and the initial textile expression, which also affects the far-field expression. The transformation modifies the textile field and also juxtaposes new expressions onto the initial design; the changes appear as relationships to the surface interaction.

Knitted Light, Touching Loops, Designing with Heat and Tactile Glow represent the initial projects and the ways the surfaces in these projects have been designed suggest basic interaction scenarios where focus is placed on the textile expression. The projects Repetition and Textile Forms in Movement belong to the second category of projects and further develop the relationship between function and expression in the design process by proposing multiple interaction expressions for a single textile surface. In these design examples, the textile expressions are more intricate and descriptive. For example in Textile Forms in movement, the design process began as explorations of the relationship between knitted surfaces and servomotors and the project came to develop basic descriptions for moving textile expressions such as primacy, arrangement, anticipation and intensity. Subsequently, the examples were used to construct a common language to use when the textile and interaction frames are equally important grounds for descriptions of contextual and non-contextual spatial expressions.

Compared to a static textile, designing or designing with interactive surfaces brings a new perspective on critical variables such as depth, rhythm and spatialization, which combine programming with inherent material aesthetics. Each of the design examples aims to open for reflection on how the transformational form and interaction relate the critical variables to each other when defining the textural expression of space. What is important when studying the examples is the way the variables of different kinds of spaces, e.g. textile, interaction and architectural ones, relate to one another in the design when defining the surface expressions. These relationships between frames are introduced to be able to describe the states of transformation embedded in each textile expression. Thus, decisions
experiments and reframed in the Relational Textiles methodological framework to relate to the design perspectives of textiles, space and interaction.

2. Relational Textiles: a field of possibilities for integrating textile thinking in architectural design

Compared to the traditional, static representation methods in architecture such as perspective drawing and physical modeling, digital methodology opened up a dynamic drawing space with unlimited scales of design and thus came to influence views on the role of the material in the design process. Due to digitalization, the hidden dimension of the textile structure becomes a visible dimension in architectural design in this context. Accordingly, knowledge of textile construction techniques becomes influential as translations of structural design processes in architectural design and these new processes mark the intersection between digital environments and new three-dimensional printing possibilities. As one of the fundamental textile techniques, knitting can be translated into different scales by computation, which in turn opens the textile structural scale for surface design processes in architecture, as Palz’s research illustrates. This is one way in which it is possible for textile knowledge and architectural design to intersect, i.e. by using textiles as methods for surface construction in which the surface geometry is translated to another scale through material reduction and later reproduced in another material form (three-dimensional printing) and scale.

In this thesis, the explorations of surface expressions through interactive textiles aimed to design a hybrid material tool that would be capable of expressing the direct design of the surface by combining textiles and computation. The design program Relational Textiles for Space Design established a structure that enables relating the abstract virtual space to a fundamental material expressive scale such as, in this context, the textile dimension.

The surfaces developed in the experimental projects give rise to questions to be asked during a design process in which the interaction and the textile expression are simultaneously enriched and form a design cycle. These questions refer to the depth of the static and transformational expressions of the textile as connected to the interaction in space or to the methodology required to relate the pattern change expressed by the initial surface design in connection to the design of the interaction frame. These two directions, which have been developed in the research presented in this thesis, are related to Hallnäs’s four fundamental criteria to describe the methodology of interaction design: spacing, timing, connectivity and methodology. These directions have been developed in the design experiments and reframed in the Relational Textiles methodological framework to relate to the design perspectives of textiles, space and interaction.

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The ability to relate the Relational Textiles space to existing methods in architecture gives rise to new issues that needs to be addressed. For which levels of the design process may these textiles be integrated? Possible answers to this question may suggest complementing digital tools for surface modeling with a physical surface representation implemented
In a circular design process or to explore and integrate final expressions directly as interactive textures in a spatial design. As was illustrated in the section on related research, the way to integrate textiles into computational thinking in the architectural design open up for different perspectives, and their integration is dependent on the initial definition of character of the textile, e.g. as a material expression or construction method in the spatial design process. What is important here is to be aware of how the textile is viewed, i.e. as a method or an expression, and to understand what kind of prototyping space the textile is introduced into. The matrix below presents a basic structure for reflecting on the level of surface prototyping that relate the material (the textile) to the space of prototyping (physical/digital). In the matrix, examples of related research (examples 1-3) have been placed together with the design examples presented in this thesis (example 4).

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Matrix for discussions on the level of prototyping

In Example 1, the textile is considered to be a structural method that informs the physical prototyping space. Example 1 refers to research projects such as Bosu (Parkes and Ishi, 2010), which exemplifies research on the development of new design tools for designers as they combine computation with physical material representation to propose new sketching methods for various design processes.

In Example 2, the textile is considered to be a structural method that informs the digital prototyping space. Example 2 represents research projects conducted by Menges and Ahlquist. They explore the complexity of form generation and the circularity of the design process between the physical material behaviors and digital environments such as Processing, Java and Grasshopper and propose a better connectivity between digital and physical spaces. Thus, they develop possible methods to integrate textile variables directly into digital prototyping.

In Example 3, prototyping at the real-world scale, Ramsgard Thomsen’s work brings together different perspectives on textiles and computation. She explores the textile character in relation to the dynamics of form in the digital space and goes on to perform prototyping in the physical space; her perspective explores both micro and macro levels in textile thinking while leaving the matter of how questions from interaction aesthetics should be addressed in relation to the surface expression open.

In Example 4, Relational Textiles open a research space for interactive textiles in which prototyping starts in the textile expression in the physical space and goes on to inform the digital space during the design process. The ways in which the textile expressions are presented refer to the methods behind them and functions as a method of relating design variables from textile, interaction and architecture to each other. Regarding space design, Relational Textiles function as complementary tools to discuss surface aesthetics while simultaneously informing digital prototyping.

Although the matrix in which these examples of related research are presented divides them according to their views on textiles and their level of prototyping, synergies can be created between these different perspectives on textiles and architecture. These synergies are addressed in the discussion below and can be seen as a possible direction for further research.

 textiles as a method: reflecting on digital form-making processes. The materials developed in the design examples presented in this thesis may open a hybrid space for the development of new methods to explore different dimensions that textiles are able to express. Thus, the materials can be related to the experiments and projects from the field of interaction design such as Bosu (Parkes and Ishi, 2010). Each of the textile examples in this thesis can also be regarded an aesthetic design tool for prototyping with textiles and the surface variables of the textile examples can be explored at the textile scale by designers and reformed into new expressions due to the computational character of the surface. Combining computation with physical textiles (materials) provides a complex understanding of the different spatial relationships that may be embedded in and expressed by the textile surface, while also controlling and exploring the transformational scale and expression of the space through direct interaction with the material.
Menges and Ahlquist’s research focuses on the exploration of static textile behaviors from a performance-based perspective. Discussing the experiments from the perspective of the digital surface methodology of architecture and relating it to Menges and Ahlquist’s research, one way of viewing the results of this thesis is to open for reflection on the circularity between digital environments for prototyping and computational textiles from an aesthetic perspective in the design process, thereby proposing an alternative way of describing the material expressiveness, and also to open for the development of new methods to directly integrate the design variables of interactive textiles in the digital form-making process.

- textiles as an expression: reflecting on prototyping at the real-world scale.
By envisioning different kinds of spatial scenarios, the work presented in this thesis aims to bridge different spaces where computation and architecture are involved in closer forms of communication regarding textile representation. Although the scenarios have not been constructed exclusively in the physical space, the surfaces designed in this thesis relate to Ramsgard Thomsen’s work as they develop the knowledge of knitted constructions in relation to the notions and methodology of interaction design. The examples in this thesis open possibilities for surface prototyping at the real-world scale with dynamic physical structures, and they also express the direct relationship between the interaction and the material representation while still allowing the designer to explore and modify, in real-time, the different scales of expression such as patterns, depth and texture when using a digital environment. Subsequently, the methodology developed in this thesis complements with a interdisciplinary language to be used when designing spatial interactions in relation to the textile (material) expressiveness.

3. Relational Textiles: formal consequences for space design

Leaving surface construction methodology behind and instead considering Relational Textiles as material for design, their expressive potential has consequences for space design. The main consequence is that the idea of static form is replaced by the idea of interactive. Space defined by interactive textile forms opens up for new considerations as, in this design space, dynamic principles of composition are defined as relationships between near-field and far-field expressions in relation to spatial interaction and materialized by changes in the surface expression. Accordingly, these textiles provide a foundation to discuss new formal principles regarding the composition of space based on the surface organization (transformational form) and the interaction form; they link the textile to the architectural form, i.e. through the changing depth of their expressions as related to the acts of presence in space. Connecting the space opened by the research presented in this thesis to Buchanan’s perspective on design, “As a liberal art of technological culture, design points towards a new attitude about the appearance of products” (Buchanan, 1995, p. 19), the methods proposed by Relational Textiles for Space Design raise questions regarding surface design methodology and its role in creating an alternative textile aesthetics for built environments. As a result, they open for reflections on how future spaces may be designed and, consequently, experienced in everyday life.
REFERENCES

IX. References


REFERENCES


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REFERENCES


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Papers

List of appended publications


PAPER 1

In architecture, buildings were restricted, for many years, to few materials such as concrete, bricks, wood and stones. Even the concept of the curtain wall transformed the façade into a formal element that gave freedom in the material choice; until recently the aesthetic qualities of surfaces played a secondary role in building design compared to the importance of form and structure of the building (C. Schittich, 2006, p.586).

The recent developments in digital technology that introduced computer based renderings in the design process gave architecture drawing more freedom in surface expression. The depth of the surface is no longer expressed in just two dimensions through colours and patterns but also by three-dimensional exploration of the surface. The honesty in volume and surface expression present in the Modernist Movement has been dramatized in present architecture by the exaggerated scale of textures that appeal to our senses. Therefore, the visual and emotional qualities of the materials in contemporary architecture became as important as their functional qualities.

Rapid development in technology and communication in the recent years pushed architectural design towards rethinking the design process through spaces and materials for a better form of living closer to the human physical and psychological needs for well being. The tendency now, in building design, is to search for innovative materials that besides their aesthetic and functional values could act in dynamic ways offering a higher capacity of decoration, more flexibility, more functions and low weight to the building structure.

The latest developments in the material field changed the classical static perception of surfaces. Surfaces are capable to visual and physical transformation, to integrate specific functions regarding light control or technology, to transport information. Architectural surfaces became in this context “sensitive skins”, a new concept inspired from the complexity of the organic life that defines materials that beside their aesthetic value hide functional complexity due to their specialized cells (Schoof, 2006, p.25).
Textiles have always been around us in different forms. Textiles have both functional and aesthetic values for us just as the human skin. We associate them with the feeling of warmth and protection. Our perception of textile surfaces combines both visual and tactile emotions. From the use of textiles to cover the body, the role of textiles extended to exterior environment. Our multi-sensory experience with textiles in the privacy of our homes or as body cover made our relationship with textiles very natural.

Alongside with glass, textiles are conventional materials for architectural design that mediate our relationship with light. Their role in this context combines textiles’ functional potential regarding light transmittance and aesthetic values as façade decoration. Developments made in the quality of glass excluded textiles as part of the building façade both for esthetic reasons such as openness and transparency but also for functional reasons as low resistance to sun light, to fire and low artifistic values. Their limited properties transformed textiles for many years into rather dull and classic material when used in this context.

The latest developments in textile design changed the classical image of textiles and reintroduced them in all fields of design as intelligent soft surfaces capable to integrate specific functions regarding light control or technology to transport information.

**Why textiles?**

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The latest developments in textile design changed the classical image of textiles and reintroduced them in all fields of design as intelligent soft surfaces capable to integrate specific functions regarding light control or technology to transport information.

**Design vision**

Starting from the relation between light, textile and space, the present project proposes a vision of textiles as an interface between interior and exterior as part of building façades. The purpose of the project is to reintroduce textiles as an alternative for the functional and esthetic layers in the glass by being applied to the interior part of the façade, to create a textile interface that through the interaction with light between the indoor and outdoor environment offers architects an advanced textile complement to the conventional materials in building design.

The present project is an investigative work that experiments with the combination of light and textiles in different ways having as objective to not a finished product but different prototype ideas. Through the exploration of different prototypes, the aim of project is to demonstrate the high potential of textile materials as alternatives to the classical surfaces used in architecture. The research focuses on the area of advanced textile materials that by their intrinsic proprieties or combined in different systems use the interaction between textiles and light in order to reach different functional purposes and space experiences.

The design process follows two general paths: one oriented towards function having as an aim to enhance the functional potential of the material by material choice and production technique; the other towards expression by using the emotional potential of the combination of textiles and light to enhance the user’s interaction with the built environment.

The idea is to combine functional and emotional aspects of textiles and light in order to design diaphanous material that will filter the day light on the inside and reflect sun heat during the day and in the night will transform itself in a source of light.

The materials used such as polyester monofilament and metal yarns are on the border between textile and architectural design. The textile technique was used to create the bindings in between them was knitting. Although knitting is more connected to wearable garments the combination of materials as metal and transparent polyester gives knitting another approach.

Since a major thought during the design process was to use to the maximum, the emotional role of textiles in the build environment the inspiration for surface design has skin as major theme. During the design process cellular structures were constructed in different ways using partial knitting in order to give surface volume, an organic appearance but also enhanced tactile proprieties.

**Result**

The result of the project consists of different prototype ideas that illustrate different possibilities to combine textiles with light in order to create an interactive environment. The design process explores different ideas generated by this combination starting from two relationships light prevails the textiles, the textiles prevails the light.

The resulted pieces generate different space experiences based on the relationship between textile and light as two elements that interact with each other in different ways. The first where textile piece prevails the light refers to the relationship between the natural light and the textile surface; here the textile piece acts as a filter for the light controlling its intensity through its structure. The second interaction, light prevails the textiles refers to the relationship between the artificial light and the textile piece; in this case the placement and the intensity of the light controls the perception of the textiles by making certain parts visible and other parts disappear.

Each of the prototypes develops a specific idea based on the effect created by light and its surface. Alongside with the aesthetical values given by the exploration of the relation between textiles and light, the project has a strong technical approach by exploring different possibilities to integrate light into the textile structures and to create three-dimensional surfaces using knitting as a technique.

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**Why textiles?**

Textiles have always been around us in different forms. Textiles have both functional and aesthetic values for us just as the human skin. We associate them with the feeling of warmth and protection. Our perception of textile surfaces combines both visual and tactile emotions. From the use of textiles to cover the body, the role of textiles extended to exterior environment. Our multi-sensory experience with textiles in the privacy of our homes or as body cover made our relationship with textiles very natural.

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Streams of light

Streams of light is a translucent knitted textile that lets the light penetrating its skin through holes in its structure. The shimmering shadow transforms the interior space through its presence on the surfaces. Its three-dimensional shape is orientated after the sun. The metal inside acts as a protective skin that reflects the sun’s heat to the outside. The moving panels are capable to adjust and redirect the light on the inside. The play with light and shadow on its surface adds more depth and value to the flat glass façade. The penetrating light together with the shadow left by the panels creates a dynamic pattern during the day on the interior surfaces as the light filtered by trees leaves.

Interaction

Interaction: The piece could be part of a flexible metal system that adjusts itself after the direction of sun light as response to the user’s movement in space. In this case the pattern left by its shadow on the interior surfaces becomes dynamic according to user’s position.

Produced in electronic flat knitting machines

Gauge: E12 (12 needles per inch)
Prototype size=60/60
Technique: partial knitting and ridge pattern using plating yarn feeder
Materials: stainless steel ø=0.10mm, polyester monofilament ø=0.10 mm
Repeat: width= 60 cm, height= aprox.5

Photo: Jan Berg
Moon lighter

Moon lighter is a shapeable knitted textile that changes value according to the presence of light. It envelopes the space like veil. In day light, its surface is translucent. Its functional value is to reflect the sun due to the metal inside. The glow in the dark yarn inlayed in the knitted structure charges from the UV component of light. In the night, the textile structure becomes invisible leaving the place for glow-in-the-dark to gently light up the interior space. The glass façade gains materiality during the day due to the metallic inside. The sun’s reflection is the result of the glow in the dark yarns. In the night, the textile structure becomes invisible leaving the place for glow-in-the-dark to gently light up the interior space. The glass façade gains materiality during the night due to light emitting wire. Parts of the pattern are interactive with the people passing by the building due to the electroluminescent wire present in some of the ridges. A sound sensor is connected to the wire. During the night, the strips of electroluminescent wire light up parts of the pattern as reaction to the strong sound. The wires of electroluminescent light provide both the participation of the façade to the night atmosphere and also recharge with their light the glow in the dark stripes.

Interaction

Interaction: Moonlighter is a textile interface that responds to sound by emitting light. Its dynamic pattern appears as a surprising effect in the night at high levels of sound made by the people passing by the building. The ridges of phosphorescent yarns become invisible when the electroluminescent wire is activated by the sound sensor. In the same time they are recharged with energy from the light emitted by the wire.

Produced in electronic flat knitting machines

Gauge: E12 (12 needles per inch)

Prototype size=60/60

Technique: partial knitting and ridge pattern using plating yarn feeder

Materials: stainless steel ø=0.10mm, polyester monofilament ø=0.10 mm, inlay=electroluminescent wire ø=0.9 mm, phosphorescent polyester yarn ø=10mm (7 hours of glow when charged properly)

Repeat: width= 60 cm, height= aprox. 7 cm

Fig. 3, 4. Textural shadow effect left by the textile piece under the light

Photo Jan Berg
Fig. 5, 6. Pictures showing the user interaction with the textile piece. The material lights up the space at high levels of sounds that activates the electroluminescent wire.
Drops of light

Drops of light is a knitted piece that integrates LED as sources of light. The intensity of the emitted light adjusts itself according to the values of the natural light measured by the sensor. The bindings separate the constituting materials metal and monofilament on the two faces. On the right side, the presence of metal rejects the heat on the outside and serves as conductive material for the LED’s connections. The presence of polyester monofilament separates the conductive ridges and gives the wrong side isolative values regarding heat. The material could be twisted according to the seasons. In the winter time the metal side is positioned on the interior and reflected the heat to the inside. On the summer time the metal side is oriented on the outside reflecting the heat. The light emitted by the LED varies as response to changes in the natural light values. Interaction: The piece responds to the changing levels of light by activating parts of its pattern. The piece is connected to a microcontroller. The light sensor placed on the interior environment measures light intensity of the space and sends the information to the microprocessor that according to the values in the program sends electric input to the LEDs.

Produced in electronic flat knitting machines
Gauge: E12 (12 needles per inch) Prototype size=53/60cm
Technique: ridge pattern
Materials: stainless steel ø=0.10mm, polyester monofilament ø=0.10 mm, conductive thread stainless steel coated with polyamide, LED
Repeat: width= 60 cm, height= aprox. 5 cm

Fig. 7, 8. Pictures showing the user interaction with the textile piece. The stripes of LED are controlled by a microcontroller programmed to send them electric input at low levels of the surrounding light. The shadow of the human silhouette activates parts of the pattern.

Photo Jan Berg

Reference
TOUCHING LOOPS - INTERACTIVE TACTILITY IN TEXTILES

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ABSTRACT
A collection of three different knitted material prototypes with structure-changing surfaces have been designed. The collection is named “Touching Loops” and is the result of an exploration in interactive tactile properties for knitted textiles. As a first experiment, different yarns were tried out for their ability to change structure due to heat in several knitted constructions. The experiment resulted in three different material prototypes with the ability to sense touch and react by shrinking, breaking or hardening. The aim of the project is to explore new possibilities for interactive tactile knitted materials and structures. In the discussion we relate to these textile structures as possible materials in the context of architecture.

1. INTRODUCTION
The sense of touch is an important feature in both interaction design and textile design. In interaction design tactility is used as a functional asset to control an interface. There are several examples of how you need to use your body for this purpose; such as pressing a button to answer to your mobile phone but also where your whole body is needed to control interfaces for electronically based products, for example when playing computer games. The importance of tactile sensing in textile design is also essential but it refers to different values compared to interaction design. Used as main material in the first forms of archetypal inhabitation or as body covering, our special relation to textiles has a long history that is based on tactile emotions and the feeling of protection. In relation to our body, textiles are meant to be worn or to ensure our comfort when placed on furniture. Besides the feeling of comfort that comes from their softness, tactility in textiles also refers to the quality of the material to raise an emotional value when the human body gets in contact with it. The softness of the material and the diverse tactile perceptions of a textile surface are based on the structural
design and on the properties of the yarns combined in the textile structure. The wide possibility to vary the structure of the material and the combination of yarns makes textiles an ideal support to integrate complex functions along side with their protective role. The recent development in the area of interactive textiles that combine the softness of the material with its capacity to sense and respond has brought textile design close to the discipline of interaction design. Combining interactive and tactile properties in textiles offers new possibilities to design interfaces. By using conductive yarns and electronic components, computationally active textiles can be designed (Post et al. 2000) such as soft interfaces that react to the user’s stimuli. With the ability to change the structure, temperature or form, textiles are able to react on different kinds of input that makes it possible to experience different kind of information in textile materials.

An example of a project that has explored the idea of transforming textiles is the design of the dresses “Kukkia and Vilkas”. In this project, a shape memory alloy has been integrated into two kinetic electronic garments that are able to change shape over time (Bezowska & Coelho 2005). Another example in this area of research comes from the Tangible Media Group at MIT Media Lab, that have designed an interactive membrane coupling tactile- kinaesthetic input with tactile and visual output. The membrane consists of an array of individual actuators that use changes in orientation to display images or physical gestures (Raffle et al. 2004).

This paper reports on an experimental project where a textile material able to sense and to respond to external stimuli has been designed. The aim of the research has been to explore new possibilities for tactile and interactive properties in knitted textile materials and structures.

2. EXPERIMENTS AND MATERIAL PROTOTYPES

The project started out with a first material experiment where material with properties capable to change shape was searched for. Several knitted pieces were made and their abilities to generate heat and change shape were tried out. The experiment resulted in three different material prototypes connected to a power source and a microcontroller. The prototypes are able to sense touch and to react by being heated and change shape.

2.1 Knitting construction

The research investigates the integration of conductive yarns and heat-changeable materials in a textile structural technique such as knitting using structural and Jacquard patterns. Aesthetics have been combined with functionality in order to explore different tactile feelings given by the structural patterns and in the same time to investigate the integration of conductive and heat-transformable yarns that could work together with the knitted patterns.

The developing process meant programming the patterns for the industrial machine Stoll CMS 330 TC in such a way that the conductive silver yarns also play an important part in the material’s aesthetics besides their function to emit heat. The transformable yarns were subtly integrated into the bindings to react to heat when the material was touched. The result of the process consists in three knitted pieces that are able to transform in different ways due to the different properties of the integrated yarns and to the emitted heat as reaction to the passage of the current trough the conductive yarns. The silver coated copper yarn used is a conductive yarn that should not change the elastic quality of the material and in the same time be a high conductive material that will not necessitate high intensity of electrical current.
ways of connecting the power source to the textiles were tested. The power supply was due to heat. A power supply able to provide 30 Volts and 5 Ampere was used and different

In the first experiment, several small textile samples were tested for shape changing properties. The materials for the three material prototypes developed after the first experiment, were chosen for their ability to sense and react on heat. They were connected to the same power supply used in the first experiment, and around 1.7 Voltage and 2-3 Amperes are supplied for ten seconds to create an aesthetical and visible shape changing reaction.

2.3 Sensing

The conductive yarn used for the three material prototypes are not only providing heat to the textiles, it also enables the textiles with touch sensing properties. Since some of the conductive yarn rows are supplied with a small amount of power, when touching two of the rows with a finger, a small amount of current is running through the skin so that an electrical circuit is closed. A microcontroller that is connected to the textile is able to sense these incoming signals and to react by turning the power supply on. Depending on the microcontroller programme, the textiles are able to react directly to touch or react after a delay.

By using the conductive yarn to sense touch and for generating heat, the textiles function both as tactile input (touch sensing) and tactile output (heat generating and reacting by breaking, harden or shrinking).

2.4 Result

The exploration resulted in three different material prototypes where the aesthetic expression is closely related to the textiles’ properties of changing shape and their ability to sense touch. The experiments and development of the material prototypes show that the shape-changing properties in the textiles depend on how much power that is supplied, the knitting technique and the type of connection to the power source etc. Due to those variables, the material is able to react in a subtle or a clear way. The interactive properties and expressiveness of the material is also depending on the programming of the microcontroller that turn the power on and off in the textiles.

3. INTERACTIVE TACTILITY IN TEXTILES - possible scenarios for architecture

The integration of basic concepts such as adapting and flexibility as variables in architecture changed the conventional way of designing buildings. By challenging the limits of the existing rigid spatial design, a new type of architecture has been proposed; one that “adapts, rather then stagnates; transforms rather then restricts; its motive rather then static; interacts with the user, rather than inhibits.” (Kronenburg 2007). The new spatial context exceeds the limits of conventional architectural design by having as major aim to create emotional connection to the user besides just physical enclosure. In this case the flexibility of the structure is followed by the emotional role of the material as a way to connect the user more physically and emotionally to the inhabited space (Schittich 2006). Computer technology offers new possibilities for the traditional materials in architecture to express their aesthetic and haptic properties of the surface in order to appeal to the user emotions.

By using tactility as an initiator, the present project links different field of design such as textile design, interaction design and architecture in order to generate new material ideas using textiles as support, instead of the architectural conventional materials. The experiments done during this project used computerised machines to create different interactive knitted surfaces. By means of creating different structural knitted patterns, the aim of our project was interesting samples were those that were knitted so that the conductive yarns were in rows and not knitted in bigger areas. Those textiles were more likely to react to heat at all.
not to offer a concrete product result but to generate new thoughts on how interactive textiles surfaces controlled by hand or body movement could contribute to the sensorial relation between the user and the built space. The research done shows the possibilities of a traditional textile technique such as knitting linked to the production of wearable garments, which placed in an interdisciplinary context, is explored in such a way as to generate new ideas for another field of design in this case architecture.

We believe that our present research in transformable textiles relates to the research in architecture design towards building new flexible spaces that will challenge the user’s sensorial experiences. Exploring soft, transformable textile surfaces compared to the hardness of the material palette already present in architecture design will offer an unrestricted sensorial exchange between the inhabitant and the space. The natural relation of textiles and the human body makes it natural for a user to experience emotional values hidden in the textile structure, and will not inhibit the user to physically discover their surface. Tactile, responsive textile finishes will encourage the physical participation of the user to discover the space. The tactile interaction with the surfaces will not limit the space just to the visual perception; it will extend its emotional potential by giving space a tangible dimension.

4. CONCLUSION

The pieces that we have designed in the Touching Loops project are a first step in exploring the area in-between interaction design, textiles and architecture. The objective was not a finished product but different prototype ideas that demonstrate the high emotional potential of the textiles in the built space. We found it interesting to be able to adapt a form of a material after it has been produced. With shrinking, stiffening or breaking properties, we can design aesthetical expressions and adapt the form to the purpose of applying heat directly in the textile.

5. REFERENCES


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Interactive Textile Expressions in Spatial Design: Architecture as Synesthetic Expression

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Abstract: Extending the role of the surface from just an embellishment of the tectonics to communicative devices challenges the traditional design process in architecture. Through a series of design examples, the paper presents a research program that introduces and discusses a new grammar of ornamentation generated by the relation between surface expression and the act of use in the build space. Projects such as Knitted light, Touching loops, Designing with heat and Tactile glow are examples meant to analyze the relation between material, space, time and interaction expression through the design of three dimensional knitted interactive textile structures. The design process joins together different design fields such as architectural, textile and interaction design in order to re-define the relation between human being and space. The design process starts with the microstructure of the textile element and ends with the space design using the interaction design as a tool to relate the human presence to space. The paper aims to propose new interactive spatial expressions created by the integration of computational technology into soft interactive textile surfaces that enable the user to perceive the complexity of the architectural space through a synesthetic perception, that exceeds the limits of visuality.

Keywords: Architecture, 3d Knitted Textiles, Interactive, Synesthetic

Material Expressions

Surface ornamentation has often been considered an addition to the pure form in architectural design (Lloyd, 2007, p.03), and thus, a subject of debate. The way surface expression was stylized, designed and executed linked the architectural expression to a certain historical time and cultural context of our society (Domeisen, 2008, p.120).

The Modern Movement in architecture declined any stylization of the surface. The material had a neutral role in surface expression (Frampton, 2007, p.369)- it was considered a means to build the shape of the space. The aesthetics of functionality was introduced at that time as opposed to the classicist architecture - objects were meant to be designed in accordance with their function. To transform the material expression of the surface from a neutral element to a stylized element, by adding different materials, patterns and colours was seen as a way to aestheticize the form. Postmodernist theory declined the purist modernist ideals and re-interpreted the surface ornamentation from another perspective, “more is not less”(Venturi, 1966, p.22). The term introduced the idea of contextual ornamentation as a mix between old and new elements and the popular symbolism. Perhaps one way to reconcile the relationship between form and ornament is the new approach that architectural design has presented, blurring the contours between structure and ornament (Ruy, 2009, p.13). The design of fluid
spaces refers not only to the way to design spaces through complex geometrical shapes but also refers to the expressive materiality of the surfaces. The language of ornamentation is being reinterpreted in current architectural design by transforming the embellishment of the tectonics into plastic structural forms in order to generate new architectural expressions.

Architecture and Textiles – Design Connections

An early analogy between textile design and architecture is given in Semper’s architectural theory that connects textile art to architectural design by giving textile structure a symbolic meaning, linking imagination to craft by the physical representation of the object (cf Hvattum, 2004, p. 83).

Describing the new methodologies of architectural design today, Garcia also refers to them as a “textile way of thinking architectural design” (Garcia, 2006, p. 8). His definition refers not only to the specific terminology used when describing fluidity of spaces, such as veils and curtains, or to its structural design, connecting it to the traditional structure-based textile techniques such as weaving, knitting, etc., (fig 1,2), he also refers to the use of textile surfaces as new forms of materiality in space design.

“Soft textile foundations are fundamentally changing the way we think about our build environment” write Beesley and Hanna (Beesley, Hanna, 2005, p. 103) referring to the new typologies of structural design. The expression of space in architecture today focuses on the module as a pattern for the surface structure and design. In this new architectural design, the aesthetics of the space have a close correspondence to the aesthetics of structural textile design – the ornament/module is embedded in the built structure in the same way as the textile binding; the difference is the scale of physical representation. The geometry of the architectural module is seen as a multiplying form to build the surface and its ornament - the same design principle that is used in textile design when creating structural patterns in weave, knit or braiding.

Abandoned for a while by the modern architectural material palette, textiles are presently rediscovered due to the qualities of their surface such as flexibility, softness or adaptability to the building’s complex shape. Transformable textile surfaces motivate research in architecture to investigate dynamic typologies of spaces and new methodologies of design. Inspired by the process of morphogenesis in nature, Mette Ramsgard Thomsen explores in “Robotic membranes”(Ramsgard Thomsen, 2007, p. 37), the dynamic behavior of space; interactive textile constructions act as a lively organism changing shape to external and internal stimuli. In the design of “Implant Matrix” (Beesley, Elsworth, 2006, p. 169) Beesley and Elsworth investigate the intersection between textile design and architecture, envisioning responsive geotextiles as earth reinforcements or as buildings surfaces that transform according to human presence.

The advances made in textile technologies opened up the field of textiles to the research in other fields of design. Used as hybrid products or as composite materials in architecture, textiles are “ideal” materials to provide a soft interface between the user and the hard architectural surfaces or to integrate the advanced technologies to be included in the future building systems (Braddock, O’Mahony, 2005, p. 162).

Design Program

The aim of the design program is to explore the integration of interactive textile surfaces into space design and reflect upon the role of dynamic materials as part of the space expression. Through a series of experiments, the design program presents examples of new dynamic expressions in architectural design by analyzing the relationship between space, material expression and human interaction. The program introduces technology as part of the expression in space design by relating the aesthetics of the space to the users’ actions having the material surface as mediator. The idea is to explore the acts of use in space and the surface transformation through tactile and visual change, to relate the human presence to the space by playing with different scales and dimensions of expression; from the near field expressions linked to the scale of the textile material structure and to the far field expressions that connects to the overall scale of the space.

Motivations of the Design Program

To introduce multisensorial elements in the space design means exceeding the visual communication tools used in the architectural design. The investigation of dynamic surfaces, in this context, requires a more appropriate method of investigation that merges different design fields such as textile design, interaction design and architecture. Integrating computational technology to the new architectural surfaces challenges the design process and offers novel possibilities to stimulate human interaction in space. Extending the role of the surface to a communicative device, relating its scale to immediate human interaction, opens up for new relational expressions to the architectural space. In this context, the material acts as an intermediary between human and space. Translated to textiles, the hard part of the electronics becomes a soft user interface. The material expression links the space design to the user; its textile expression exceeds the visual boundaries of the architectural space leaving space for the other senses to interplay.
Design Elements

Interaction Expression

Using interaction as part of the space expression integrates users’ actions into the space design. The expressions of interaction, in this case, refer to the actions that connect the acts of use in the space to the way the space transforms and consists of hand or body movements. Depending on the act of use, the surface changes appearance. The interaction expression links the physical and visual perception in a synesthetic expression through the visual and tactile changes in the pattern of the textile surface.

Examples

The project Tactile Glow explores the direct interaction between the user and the textile surface; a tactile pattern is related to a visual transformation of the surface. The textile shape acts like a switch to activate light patterns on the textile surface.

The surface’s response in Tactile Glow is complex; by touching a certain shape, several modules of light are activated in a chain reaction. The expression of interaction in Tactile Glow is based on elementary actions in a dark space- I touch a button and I turn on the light. Three different switch shapes are integrated into the textile modules acting as light switches. A certain colour of light corresponds to each shape: pressing the triangular shape a white light is activated, a red light is activated when pressing a circular shape and a blue light is emitted when a squared switch is pressed (fig. 3, 4).

The expressions of interaction vary with the dynamic of the natural light. The shape of the textile switch is visible during the day. You can see the shape and choose which one to press. During the night, when the space is dark, there is another type of interaction with the textile surface. The switch’s shape is not visible and the surface can only be touched by chance. Some of the modules are connected in an electric circuit that enables the user to activate a single, large shape of light. Complex pattern combinations can be created by simultaneously pressing certain areas and activating more shapes of light at the same time (fig. 5, 6, 7).

The light pattern design of the textile surface is an open design, depending on the user’s position and actions on the textile structure. The expression of interaction and the space expressions are connected. The space expression is not static; its dynamic pattern is dependent on the acts of use. The project Knitted Light investigates the design of interactive textile structures placed on the border between internal and external space, specifically on glass facades. They act as interfaces that trace people’s movement (Dumitrescu, 2008).

Compared to Tactile Glow, human presence in space is an event in Knitted light that is sensed in a different way. The expression of interaction, in this project, is based on the sound you make as you move in the space. Moonlighter is a textile light structure that it is activated by the sound of people’s voice and body movement. Sound levels are measured by a sound sensor and translated into light due to the electroluminescent wire integrated into the textile structure (fig. 8, 9).
Random sound patterns generated by people’s movements in space are translated into the visual transformation of the pattern of the textile structure. As long as people are walking or talking the space is “alive”, lit up by the textile veils.

In *Drops of light*, light sensors attached to the textile’s structures measure the light levels in the building. The movement of human shadow in space is traced by the light sensors in *Drops of light* causing LED sources to fade. The space visibility and the human movement are connected through visual parameters due to the dynamic of light structures (fig. 10, 11).

In *Knitted light* the interaction with the surface is not done by direct manipulation; the textile surface responds to human presence from a distance in an unexpected way. The pattern of light of the textile structure is controlled by the sound that people are producing in space or by the movement of their shadow. Without the human presence the textile surface and the space are static; no light, transformation, or pattern is created. Depending on where the light or sound sensors are placed in relation to the building, different scenarios of interaction could be envisioned. In *Moonlighter*, the placement of the sound sensor outside the building could bring a visual comfort to the people passing outside the building by lighting up the façade during the night; placed on the inside the sound sensor acts like a light switch for the people present in the building. In both projects such as *Knitted Light* and *Tactile Glow*, the design of the light pattern is not a fixed designed. The design depends on time of the day, on people’s actions in space and the position of the sensors in relation to the building. Including interaction expression in the space design changes the static conventional expression of space. Interactive surfaces transform space into a dynamic environment, linked to the element of time and the actions of the visitors.

**Material Expression**

Material expression was the quintessential element in the design process of each of the examples in the design program. Textiles are an ideal material to facilitate surface interaction due to their natural relation to our body, and also due to the extended possibilities of varying properties and the design of textile structure. The design process of each of the examples presented here started from a detailed perspective, the design of a textile structure. Compared to the traditional materials used in architecture, the expressiveness of textile materials results both from the pattern design (visual characteristics) and from their tactile properties— the way the structure feels to our hands. The diverse qualities of the structure and of the yarns used enable us to design with a double focus on visual and tactile expressions.

**Examples**

The material expression in *Knitted light* explores the relationship between light, textile structure and space design. The textile structure is designed to sense, reflect, filter and emit light. Steel yarns and stiff plastic yarns that are part of the architectural material palette, have been used to knit the textile structures. A traditional textile technique that is used to create garments for fashion was put in another material context in order to create an architectural textile expression. It is a material that is inspired by the transparency of the glass, in which the features of the material design are solely expressed visually, as opposed to the familiar tactile expressions of a traditional textile (fig. 12, 13, 14).
The tactile translation of light is the main exploratory theme in the project *Tactile Glow*. The porous surface of the felted wool reflects the light at uneven angles. Textile modules are designed with relation to the human interaction; the softness of their textile surface invites touched. The modules have a rough visual appearance, due to the characteristics of the felted structure, yet they are fine to touch and keep the discrete natural scent of the ship. The technology is integrated in a subtle way, hidden under the surface of the textile that gives wool felt a new material expression. The textile felt is cut and three-dimensionally shaped by heat pressing. After being heat shaped, the textile switches are needle felted (fig. 15, 16) on the surface of each of the modules. The material is gentle to the touch compared with a plastic mould and still is stable enough to support the overall structure of the surface (fig. 17, 18).

In the project *Touching loops* the relationship between the physical transformation of the pattern and its tactile dimension are investigated (Dumitrescu, Persson, 2008). The tactile qualities of textile structures are integrated into the material aesthetics and transferred later to the overall spatial expression. The expression of the material surface is linked to fashion rather than to architectural design. The tactile qualities of the surface result from: the softness of the yarns used in the structure, the textile technique chosen to build the structure (such as knitting) and the different structural patterns investigated in the material expression. The conductive yarns integrated in the structure also contribute to the material aesthetics; they are as soft as the transformable yarns. White feathery wall coverings are capable of transforming both in a visual and tactile way (fig. 19, 20, 21); when touched the material surface melts, becomes stiff or shrinks.
The way surface aesthetics are expressed in the textile design depends on the structural technique chosen to build the structure such as weaving, knitting or braiding, but also on the qualities of the yarns integrated into the structure. In the given research project examples, the design of the different space expressions starts with the microstructure of the textile material, which connects the near field expression of the textile structural pattern to the far field expression of the surface. The integration of interactive materials transforms the textile structure into an interface, capable of sensing and reacting. Adding interactivity as an asset enlarges the expressional value of the material.

**Technological Issues**

When using textiles as a medium for interaction, we replace the hard traditional expressions of technological interfaces with the softness and flexibility of the textile structures. The material, the interaction and the technical details are considered interdependent in the design process. The introduction of electrical and computerized technology makes the design process complex. In all the examples, the technical issues are solved in such a way so the textile surface still remains a design material and not just a functional interface.

**Examples**

In *Knitted Light* the conductive yarns and the light sources are integrated directly into the material, as part of the material aesthetics. The main challenge of the design process was to reach the desired material expressions through the use of unconventional materials such as stiff yarns like steel and polyester monofilament or the electroluminescent wire within a traditional textile technique.

In *Tactile glow* the focus is to hide the electrical circuits under the textile structure; that is why the modules consist of two layers of textiles with different polarities. When touched the felted shapes on the modules act like switches that connect the two layers (fig. 22). By pressing the felted switch, the two layers join closing the circuit and turning on the LED lights. Consequently, more modules are connected in the same circuit- when one is pressed, it activates the rest.

In the *Touching Loops* and *Designing with heat* experiments, the circuits are knitted so they will work both as sensors and as actuators (Dumitrescu, Persson, 2009). The electrical design and the knitted structural design are linked to each other making the technology part of the material aesthetics. Issues such as the integration of conductive yarns or light elements in the textile structure or the programming of the microcontrollers to receive and give input in the right way are also an important part of the design process. The perspectives of technology opened up the experimental design process making the interplay between textile design, interaction design and architectural design more visible.

**Space Expressions**

The focus of the examples presented in this article is to explore the combination of textile design and computation as a manner of expanding human interaction in the architectural space by facilitating the relationship between the user and the built environment, and also to generate new expressions for the built space.

**Examples**

*Touching loops* investigates the irreversible pattern transformation of the surface in relation to space expression. By touching, a surface transforms in terms of shape, structure, and temperature. The surfaces in *Touching loops* are designed for a tactile exploration of spatial surfaces. Tactile information and visual information are merged into a complex pattern. The human presence in space is traced by the textile walls. The walls are not stable entities; they transform to the human touch. The textile surface changes from fragile to stiff, from stable it breaks and from loose it contracts. (fig 23, 24).
The changes in textile tactile patterns are irreversible in Touching Loops. The randomness of human touch on the wall surface is influencing the material transformation from a near field expression. The synesthetic relationship between tactility and geometry of textile patterns is explored in the project Designing with heat; the space expression relies in the eyes of the skin. Surfaces are offering feedback to the human touch by activating the tactile heat patterns. The near field expression of the surface is somewhere in between a textile material or a plastic mould. The shrinking yarns used in the knitted structure conceal the loops. Geometrical patterns are hidden under the material surface. The material attractiveness is tactile due to the interactive heat pattern; from the simplicity of the far field space expression to the complexity in the near field expression (fig. 25, 26, 27).

Producing shifts between visual and tactile information in building materials generates complex interactive spatial expressions. By adding tactile responsive textile surfaces, the user’s interaction in space aims to exceed the visual perception of space through the combination of different design dimensions.

The textile structure in Tactile Glow generates a complex space where the user can lay, move, see or just simply touch to initiate material transformation. In Tactile Glow, the final design of the textile spatial structure has multiple field expressions depending on the acts of use. From a distance a dynamic play between light shapes can be visualized. From a closer perspective the expression becomes complex and participatory. The soft switches are placed on the surface in the areas where they can be reached easily by the human hand. Including tactility as an asset to near field expression allows people to feel the surface, subsequently influencing its expression from the far field (fig 28, 29). From far away the textile tactile modules become invisible, leaving the overall volume of shapes and light to express the space.
By adding interactive ornamentation, architecture could be perceived with different senses going beyond the purely visual perspective. The interactive expressions of the space can be viewed as a mixed reality between real elements and imaginary ones that extend our common perception by a total engagement of all senses such as in a synesthetic relationship. The dynamic expression of space is closely connected with the element of time due to human interaction. By shifting the view in the design process from the small, detailed near field design (such as the small scale of the textile structure) to the overall image, far field expression of the space, a human dimension and understanding is conveyed. This dichotomy results in a relational space (Bourriard, 2002).

Introducing Interaction Design form in Architectural Design

In Western culture, the sense of sight has always been considered the noblest of senses (Pallasmaa, 2005) and valued highest in the artistic expression. The supremacy of the view over the other senses influenced architectural design ideals. Corbusier describes the architectural design process as “pure creation of the spirit, that by forms and shapes […] provokes plastic emotions” (Le Corbusier, 1960, p. 7). The other senses such as touch (together with smell and taste) have conventionally been considered as secondary senses to the sight in space perception and consequently ignored. Architectural design ideals have been mostly addressed to the eye that transformed building design into “formal art objects frozen in space” (Mitchell, 1993, p. xiv). The user’s perception of space is envisioned by the designer as a sequence of static visual expressions. The building form is static. It is a closed design that allows the involvement of other design disciplines, in order to develop new forms of interaction in its design (fig. 30, 31). Designing in this context means designing not just a physical form but also its interaction – “the shift away from things themselves to the acts that define them in use” (Hallnäs, Redström, 2006, p.19). Designing interactive architecture makes the shift from contextual architecture to a new type of space, where design boundaries can be exceeded via user interaction.

Architectural form has always been considered as three-dimensional geometry. By integrating the notion of interaction in space design, new dynamic spatial relations can be envisioned. We act a certain way in space and we get a response at a certain time, we connect spatial form to new temporal expressions. The interactive response to the human action in space introduces the notion of time as its fourth dimension. The time in this context is not continuous as it would be in a conventional architecture, since the space expression is not stable. The time line is sequential, but interrupted by the user’s interaction, activating on and off certain spatial expressions. Introducing the time dimension in spatial design as Jones writes is to learn from participatory arts like music, dance, and theatre; it is more than designing a form, it is also “the way things are used, their lifecycles” (Jones, 1992, p. XXXii). The architectural space extends its boundaries, it situates itself on the border between the virtual and physical world- an interplay between the user’s action and surface transformation.

Jones refers to the complexity of design today, citing the design of intangible things such as a computer programs that control the changes of an interface. The idea combines form and computation into a single design. Merging the area of architectural design together with computational technologies results in new types of expressions to “support the spatialization of time” (Bullivant, 2005, p. 5) that can be defined as participatory expressions that include the human as main actor and the material-object-space as a magic instrument responding to its actions. Haque describes the role of the designer in this context to the one of “designing tools” (Haque, 2007, p.63) for people to engage in a creative dialogue with spaces. The role of the designer is to create alongside with the form an expression of use that could be modified through time such as a participatory art.

Experimental Design as Research

The design program discussed here starts out using mixed inspiration from relational art, interaction and textile design. Its aim is to open a new design space to generate and discuss new design methods in architecture. Its purpose is to generate a design process in architecture that allows the involvement of other design disciplines, in order to develop new forms of expression for building design that exceed the visual dimension. The connection between architecture, textile and interaction design is viewed as a potential way to redefine the human-space relationship by generating new material ideas from a user’s interaction.

The program refers to design situations that explore how people’s relation to the space materializes and progresses in time. The projects presented proposals on how people might
act in space and how certain material expressions can be created when different areas of design merge. The designed examples discussed here such as Tactile Glow, Knitted light, Touching Loops and Designing with heat represent initial explorations of the dynamic materiality of space from the perspective of merging textile, interaction design and architectural design. The examples introduce dynamic expressions in spatial design questioning the temporality of the space, the materiality of surface, the scale of perception and the sensorial dimension of space. New scenarios for architecture can be envisioned in this way as a method to extend the qualities of the space, relating it to the human actions. Including all the senses in designs transforms objects and spaces and enhances the user’s ability to relate to the facts and to be able “to operate in their most preferred sensory modalities”. (Krippendorff, 2006, p. 144). The combination of design methods used in this case, shifts the design process from micro details to large scale perspectives by relating the space to the user’s size and values the human presence in relation to it- from the scale of the textile structure to the scale of the architectural space. Using methods to design architecture, which include the human presence in the space, transforms the end design in a lively, transitory manner that “reflects what makes life really human.” (Jones, 1992, p.42)

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References

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Delia Dumitrescu is a designer and a researcher. She has an architect diploma and a master degree in textile design. Since 2008, Delia Dumitrescu is a Phd student at The Swedish School of Textiles, University of Borås and the Department of Computer Science and Engineering, Chalmers University of Technology, Göteborg. Delia Dumitrescu’s research explores new ways to design textile materials that join together aesthetics and computation as manner to create interactive architectural environments; it investigates new forms of expression integrated into textile knitted structures that are meant to participate actively to our space experience. Her projects have been exhibited in different exhibitions around Europe such as Stockholm Furniture Fair, Salone Satellite- Furniture Fair, Milan, Responsive by Material Sense, Berlin, Hanover and Avantex, Frankfurt.
Relational Textile Expressions for Space Design- an example of practice-based research in architectural design

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Abstract

Referring to the relationship between practice and theory in architecture, Allen defines architectural design as a material practice. He discusses the development of specific theoretical writing as naturally grounded on designed examples. Therefore, he sees the design object and the design process as “engaged reality” representing the natural connection to architectural theory, instead of grounding architectural theory on borrowed principles from other theoretical disciplines (Allen, 2000). Starting with Allen’s definition on architectural design as a material practice, this paper develops further the discussion on practice-based research methods and on the role of the artifact in development of foundational theory of architectural design. Relational Textile Expressions for Space Design is an example of practice-based research in architectural design, where research by material design aims to develop theoretical knowledge based on designed experiments.

Keywords: smart textiles, interactive textures, architecture.

Research in design-practice as foundation for design theory

The Prototype

If the natural sciences ground new knowledge on the study of natural phenomena as main object of observation, research in design builds its foundational knowledge on a different ground. As method of research, practice-based research in design builds new theory on design examples. The object of study in design research is “the artificial environment made by human beings”(Bayazit, 2004). The prototype, in this case, is both a designed object and also an analytic tool for formulating new questions to develop the knowledge for the specific field. Research, in this case, uses the design process as “empirical study” to generate new directions for the design practice (Hallnäs, 2010).
The role of the prototype becomes essential in this frame of research since it combines “the language of experience” (Stappers, 2007)- the knowledge that a designer has from his/her specific field, that serves as a contextualization for his/her research. Therefore, the design examples do not speak a neutral language. The examples represent a specific perspective that combines design skills to the language of a specific field (Biggs, 2004). By design, the model becomes a tool for interpretation. The design examples are physical objects that come closer to the real product. Hence, they represent an interpretation of what the product could become. The prototypes, in this context, are not finished products; they are conceptual tools built to be objects of experimentation and criticism. Thus, the design examples are tools of technically plausible ideation, realistic enough to illustrate design ideals (Gaver, Martin, 2000). They talk about the present but predict a future situation (Jones, 1992).

Smart Textiles as Analytic Tool for Architectural Design

My paper presents an example of practice-based research in smart textiles design. The focus of the research is to explore by design the expressional potential of smart textiles in relationship with space design. Therefore, in this paper, the design of textile material plays a central role generating both an object of design and also one of observation. The projects present explorations that focus on designing new textile expressions where surface transformation is explored by the textile design. The function of the textile prototype is to materialize different design ideas by the textile construction, where the design process is quintessential to generate primarily new knowledge for textile design. The paper opens up a design program as frame for design explorations. The role of the design program in this research is to suggest a new design area that needs to be explored. The Relational Textiles program defines a multidisciplinary design space. Consequently, the specific knowledge brought in the design process does not belong to a specific design field. Design variables from architecture, textile and interaction design gather to define various surface expressions and to materialize different design perspectives by means of textile design. The focus of this paper is to explore various space expressions of transformation by means of a textile material tool; that is to start the design from the textile structural dimension to suggest space. Therefore, the specific dimension of textile knitted structure becomes an essential element in the design process, where relationships between near field scales of design and the far field are explored. The design of the multiple layers of patterns embedded in the textile surface is not limited by the physicality of its structural design; they are further enriched by computation. Combining a physical method of prototyping to a digitalized one in the textile construction, the surface expression can be enlarged by new dynamic scales of design.

The design program aims to expand the virtual space of surface prototyping to a material one using textiles as main media for design explorations in the dynamic materiality of space. Consequently, combining computation and textiles is a way to explore the surface design by a complementary method defined by a material tool. Compared with the digital tools of modeling, the textile computational model is not material neutral. The textile prototyping tool inherits the fundamental textural properties of the textile material, opening for new expressions and interactions in space design. Accordingly, smart textiles are designed and used in this research as an expressional design tool that works in between material and immaterial spaces. Therefore, the research relates the concreteness of real scale textile material to the abstract digital space of surface prototyping in order to generate new designs.

In this context, the texture of the surface becomes a variable element to express intermediary scales of design starting from the textile construction up the scale of space. Consequently, including design variables such as transformation and sensing as variables of surface design, its texture becomes responsive opening for new interactions in space. The interactive textural scales of the surface are relative, built by the relationship between the expressions of transformation of the textile surface and the human relative position and actions in space.

The Design Process

Schön sees the role of the reflection on the design process as a fundamental method to generate new knowledge by using the experience specific for a design field and adapting it continuously to fulfill the desired vision (Schön, 1983). Combining skills and reflections as a method of research is a way to discover new patterns of work during the design process. That is to use designing both to experiment and reflect, where the “unselfconscious process” while making the design meets the “selfconscious” one of reflecting on the work (Alexander, 1964).

The role of the design process is essential in my research to explain decisions and observations based on practical work. The development of various knitted constructions together with the integration of electronics and the programming of the patterns blend together in the design process in order to explore various textile expressions. The design process has also a strong technical approach. Therefore, new methods of work using knitting as fabrication technique are developed in relationship to the textile
expression. The prototypes do not position themselves as finished products they are meant to serve as examples for further reflection when different design spaces meet. The reflective role in the design process, in this case, functions as a “corrective to overlearning” tool that describes the relationship in between making of a design and the decisions taken during the design process, as well to reformulate new ideas that come up as result of the process.

Interpreting design results

Reflecting on the outcomes from the design process, Simon’s refers to the results of the design activity as generative tool for new processes (Simon, 1996). Accordingly, the purpose of the research in design is to build foundations for new knowledge to create design, that is to extend continuously the horizon of interpretation has to inspire by the quality of design examples (Biggs, 2006). Research in design is to build foundations for new knowledge to create design, that is to develop new interpretations as generative tool for new processes not as an end statement. The outcome of research is seen as the result of the design activity as “initiation of change in manmade things”. In this context, he expands the objectives of design from the object to the actions that initiate changes in all the systems around the object from production to society (Jones, 1992).

The design discourse in practice based research builds on the interpretation of reality. Thus, it refers to future situations not to present states but uses the present state to predict the future. In this frame, the interpretation of the research results starts from a “realistic object” as tool for observation but its role is not to validate results. The outcome is to present alternative ways of designing. Accordingly, the interpretation is seen as generative tool for new processes not as an end statement. The outcome of research in design is to build foundations for new knowledge to create design, that is to develop new methods and techniques or new expressions that enlarge the design vocabulary. Biggs writes about the value of research relating it to contextualization. In this context, he defines research results as a communication channel for a specific field by which the work is acknowledged. Therefore, the interpretation has to inspire by the quality of design examples (Biggs, 2006).

Relational Textiles as Architectural Discourse

Based on the practical examples, the outcome of my research, will be discussed in relation to two directions of design methodology and that of design vocabulary.

When talking about the design methodology, the outcome of the experiments aim to build a conceptual framework for discussing design methods as result of the reflections on the design process. In this case, the designed examples are referred from the perspective of relational textiles as a design process. Shifting perspectives and placing the design examples from the perspective of relational textiles as a design result, the second direction of the outcome aims to define a material vocabulary. In this case, the designed examples are used as foundations to initiate a new design vocabulary of relational textile expressions for space design. Therefore, the outcome of the research relates two contexts for design, that of relational textiles as material by design and as material for design, bridging two design perspectives - one related to textiles design and fabrication and the other one to textiles as potential applications in architecture.

Relational Textiles as Design Process

In this context, the identity of the material is described by the relationship to its design process. So as to structure the outcome from the design process, the notion of frame of reference is introduced to describe each frame of design.

Def. The frame of reference refers to a conceptual framework that defines a design perspective.

The designed examples in this paper sum up three design perspectives that of textile, interaction and architectural design. Each textile material is defined by the relationship between the three frames of reference suggesting methods for textile design. Therefore, the design variables from each frame are related and interact with each other in the design process defining specific material end expressions.

Example: Moonlighter is one of the textile prototypes developed in this research frame. The textile is part of the bigger collection - Knitted light, where interactive knitted structures have been designed in order to complement glass facades (Dumitrescu, 2010). The project “Knitted Light” explored by design the relationship between textile patterns and space transformation in relation to the dynamic of natural light and human interaction in space.

-architectural frame
The design intention in Moonlighter is to relate different interaction spaces by textile design. The textile is able to interact and mediate between inside and outside spaces as a texture for façade and pattern for the
interior space. In this reference frame, the decisions on the scale of the pattern and position of the textile in relationship with the building were essential for the design.

-textile frame

For the textile design frame, material construction is essential in order to define surface design. The knitted structures in Moonlighter are designed in relationship with light. Therefore, the knitted structure, in this example, is designed to weave in the initial textile structure a second pattern of interactive light. The layer of artificial light in Moonlighter is embedded in the textile structure relating the light pattern to the textile-ridged texture (fig. 1). The initial knitted surface is a static design that is enlarged with new scales of changeable light patterns (fig. 2). Therefore, in the textile reference frame, design considerations on the relationship between variable and invariable textile patterns appeared essential when defining the surface layout.

 Fig. 1 near field view showing the placement of the el wire in the knitted ridges.  
 Fig. 2 near field view showing the surface texture and scale.

-interaction frame

The knitted surfaces in Moonlighter express the movement in space by the changes produced in the surface texture (fig. 3). The sound that people are making in space is expressed by the appearance of the light pattern embedded in the textile structure (fig. 4). In this frame, the relationship between possible actions in space and the changes in surface appearance were essential to define surface design.

 Fig. 3 near field view showing interactive pattern of light.  
 Fig. 4 simulation of space interaction.

-overlapping frames of design

The interactions in Moonlighter are planned as far field expressions- where textile expression and space interaction are correlated by the textile design. The metal and stiff plastic yarns used are concealing the textile tactile expression. Therefore, the material expresses far field interactions. The layer of interactive light patterns embedded in the textile surface relates to scale of the façade. Thus, the changes of the pattern can be visualized and activated from distance. The interactive light pattern enlarges the static textural textile features relating its near field expression to the far field of view. The sound in space can activate the textural patterns of light from far field positions in space (fig. 5).
Relational Textiles as Design Result

The outcome is based on the reflections on the result of the design process—textiles for design, where the end material expression brings new perspectives to space design.

Def. “Relational Textiles” describe a material design space with various fields of reference defined by the relationship between the three reference frames—textile, interaction, and architectural.

Each designed example embeds all three reference frames. In this context, the interaction design frame is variable relating to the textile frame or to the architectural frame in various ways. Therefore the textile opens a range of expressional perspectives—fields of reference for space design.

Def. The notion of field of reference, in this context, is defined as the range of expressional perspectives introduced by the textile design in space.

There are various relationships between the different frames of reference involved in the design of relational textiles for the interaction space. Each textile design introduces a field of reference in the interaction space where different "positions" in the field relate to the frames of references in various ways.

Therefore, each textile identity is described by an expression that relates to the fields of reference that introduces to space design.

Example:
Moonlighter opens a wide field of reference in the architectural space defined by far field expressions. The textile’s different scales of patterns negotiate in between different interaction spaces inside-outs. In this case, the material relational field is augmented—the near field of the textile expression is extended up to the far field by the interaction frame. Therefore, we describe Moonlighter as an expression of amplification.

Material Design as Foundation for Practice-Based Research

Doordan sees the role of materials in design research as a meeting element of various “disciplinary perspectives and methodologies” (Doordan, 2003). Smart textiles, as architectural materials bring together various design perspectives in one material concept, since the textile physical structure is enriched by computation. That is to introduce a new textile identity to the architectural design context. Therefore, this research opens up a design space where textile, interaction and architectural design meet in the design of interactive textile surfaces.

Research within the area of smart textiles expands from material fabrication and needs to communicate new knowledge to other design fields, since technological development conveys new material identities to the traditional world of textiles. The potentials of new textiles have to be accessible to the designers in order to be useful for further design explorations.

Therefore, two questions appear essential that structure the discussion on the outcome of my research:

What does it mean to materialize(expressions of space transformation through textile design)?

What is the expressional potential that this specific material brings to space design?

Designed experiments have been carried out to explore these questions and to illustrate ideas of interactive knitted textile surfaces, where the textile identity is understood primarily by fabrication. The outcome of this research translates new knowledge out of the practical work by building a common reference frame for the smart textile design merging three design perspectives. Related to fabrication, the explicit knowledge that the smart textiles’ identity brings to the architectural design field is represented by the design methodology and material expressions that appear as a result of the reflections on the design
process. Therefore, questions that link textile expression to space interaction appear essential to explore a new material space for architectural design and to generate new design knowledge.

References

PAPER 5

EXPLORING HEAT AS INTERACTIVE EXPRESSIONS FOR KNITTED STRUCTURES

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ABSTRACT

This paper describes a practice-based research project in which design experiments were conducted to explore how knitted structures can be designed with particular emphasis on various interactive heat expressions. Several heat transformable structures, able to both sense and react to human touch, were developed in the textile collection Knitted Heat. The designed textiles serve as references to reflect further on the role of interactive textiles as materials for potential designs. Specific scenarios defined by shrinking, breaking, stiffening, texturizing and warming expressed by the textile transformations exemplify and discuss their potential as complementary for other design processes.
INTRODUCTION
The last few decades have shown an extreme development of the textile material as the area of interactive, or smart, textiles has influenced the fields of industrial design, architecture and of course, the textile industry (cf. [Herzovicka and Coelho, 2005; Braddock Clarke and O’Mahoney, 2005; Colchester, 2007; McQuaid, 2005; Seymour, 2008, Ramsgaard Thomsen, 2007] etc.). Compared to “non-interactive” textiles, the concept of smart textiles primarily describes textiles whose qualities have been enriched by technology. In this context, textiles can be defined as physical materials with transformable behaviors, the materials are “augmented with the power of change and have the ability to perform or respond” (Verbüken, 2003).

Due to technical developments within computer technology such as the miniaturization of electronic components, the possibility of integrating textiles and electronic components has been demonstrated through material research and development projects. As a sequel to the concept Tangible bits - the notion of seamlessly coupling the worlds of our physical environment with cyberspace (Ishii and Ullmer, 1997), soft material interfaces such as Super Ciita Skin (Raffée, et al., 2004), Sprout I/O (Coelho and Maes, 2008) and Bouu (Parker and Ishii, 2010) have been developed as alternatives to traditional screen-and-keyboard interfaces. By sensing and reacting to physical touch, these interfaces have a kinetic memory, are transformable and engage new sensibilities. Consequently, the interest to develop new design tools that help designers to relate virtual and physical media has emerged. Projects such as Skin (Saakes, Stappers, 2009), Cabinet (Keller et al., 2006) or SandScape (Ishii et al., 2004) open the interaction design field to novel creative processes.

The concept of smart textiles opens new discussions about the role of the material in the design process and the need for bridging various design disciplines. By introducing concepts such as interaction and transformation as essential features in textiles, the textile practice faces new challenges.

This paper describes Knitted Heat, a collection consisting of the previous projects Touching Loops (Dumitrescu and Persson, 2008) and Designing with Heat (Dumitrescu and Persson, 2009), with a particular emphasis on how interactivity can extend a textile’s expressional properties as the use of conductive yarns in an advanced knitting design makes a textile become both sensitive and reactive to human touch. Knitted Heat explores possibilities to design for tactile and visual interaction as the textiles encourage a close and sensitive interaction with knitted textile material both by touching and sensing.

This project is made within the Smart Textile Design Lab at the Swedish School of Textiles and takes on an experimental approach in which design examples explore the aesthetics and emerging expressions of smart textiles rather than technical functionality (cf. [Redström et al. 2005; Worbin, 2010]).

KNITTED HEAT
Knitted Heat is a collection of several design experiments in the form of interactive textile samples, and unites two experimental projects, Touching Loops and Designing with Heat. Both projects uniquely explore the integration of heat as the focal point of the surface design.

TOUCHING LOOPS
In Touching Loops, heat is used to transform a textile surface’s structure. The outcome is three different interactive textiles able to change structure both visually and tattily. When one touches the textile by hand, the textile becomes hot and structure changes are made. The design examples show different kinds of structural changes in three different textile designs: shrinking, breaking and stiffening. The following scenario refers to all three examples, with a difference in how, the structure is changing:

1. I touch the textile with my hand and it reacts immediately by shrinking (Structure 1) or by breaking (Structure 2) or by stiffening (Structure 3) since it is programmed to generate heat as soon as it senses the presence of my skin. The textile reacts in the same area as it is being touched upon. Once it has been touched, the heat is on for 15 seconds which is considered to be enough time to make the surface react in a way that is perceivable.

2. When current is applied, the knitted patterns change size by shrinking in relation to the amount of heat and the surface area where heat appears.

3. Rows of ridge patterns are interlaced on the surface design building its texture as a structural frame. In this case, the surface does not change texturally, as it did in the previous design experiment. Instead, applying heat through the conductive yarns on the material’s ridges produces a transformation in the surface from soft to hard by stiffening specific areas.

4. When the loops are heated, conductive yarns separate the areas of the textile surface and transmitting the information as heat.

DESIGNING WITH HEAT
Designing with Heat consists of two design examples

1. Designing with Heat consists of two design examples

2. Designing with Heat consists of two design examples
developed with a focus on heat changing properties. When someone touches the textiles with their hand, the surface becomes hot in a comforting way. The textiles show two different kinds of heat design, where temperature changes produce two types of tactile patterns.

heat as soon as it senses the presence of my skin. The textile reacts in the same area that it is being touched. Once it has been touched, the heat is on for 10 seconds which is considered to be enough time to make the surface react in a way that is perceivable.

Designing with Heat: Structure 5 (Fig. 9 and Fig. 10)

This structure uses the same principles as the first design experiment but implements a different pattern design. The knitting technique in this design experiment is based on yarn inlays. The conductive yarn is inlayed in patterns instead of being knitted into the structure. Consequently, having less points of contact in between the conductive yarn and the shrinking yarn, produces a larger range of transformations in the surface design when heated. The effect appears both in shape and in size of the patterns by texturizing.

The conductive yarns are partially knitted to form three-dimensional geometric shapes creating the texture of the surface. The conductive texture changes temperature. According to which area heat is activated and the planned time sequence of the change, new heat patterns can be created as a second layer of the surface by warming the hands.

The textile reacts kind of slow and once it has been touched, the heat is on for 5 seconds in each heating area. This keeps the heating areas from cooling down as long as my hand is still touching the textile.

KNITTED HEAT

In Knitted Heat, we talk about knitting in terms of structure and texture where both elements are expressed by aesthetic and tactile qualities of the knitted surface. The experimental projects resulted in the creation of various interactive knitted patterns where the design variables of the basic knitted surfaces were enriched by computation. The design of transformations in the surface and the interaction with the surface are relating in the subtle changes that appear as material design. The knitted surfaces in Designing with Heat and Touching Loops are complex textile constructions capable of embedding various layers of information, as they are able to both sense and react.

Heat is integrated into the textiles as a means to shape new patterns or to produce changes in the surface structure. The relationship between the amount of heat and the exposure time in the conductive yarns is the key factor in shaping the material design.

Various expressions of transformation are explored in the design of knitted surfaces. Each of the examples of textile surfaces represents a specific relationship between structural pattern and the placement of conductive and shrinking yarns. The patterns, the texture and the shape of the textile surfaces are designed to allow further transformation of the knitted structures. According to the type of pattern used, the type of transformable yarn, the placement of the conductive yarn on the surface and the time settings in the computer program each of the structures allows for various states of transformation.

KNITTED HEAT AS DESIGN MATERIAL

Knitted Heat aims to advance upon new dialogues in the design process between designers and interactive textiles as material for design. That is to initiate a space where the textiles function as a meeting point between the virtual and physical design prototyping spaces. In Knitted Heat, the experiments by design combine the concreteness of the textile material with computation to create different types and scales of expression of physical and visual transformation—by breaking, stiffening, shrinking, texturizing or warming.

The expressions of heat transformation represent flexible relations in the textile surface relative to pattern, texture or shape leaving the knitted surface open for further change when placed as a material for various design processes. Accordingly, the examples are not an end design product; the result is a collection of knitted textiles whose changing behavior can be used as an open platform for surface explorations in knitted design.

Experiences of shrinking, breaking, stiffening, texturizing or warming can be further enriched when the knitted textiles are supposed to be related to various products or scales of design. Therefore Knitted Heat opens the design parameters of the textile surface design, such as shape/texture/pattern, bridging shape to material exploration in one process.

The experiments show potential ways of exploring the relationship between surface/shape, pattern/shape, textile/visual etc. in initial stages of the design process through the direct manipulation of the material when the scale of prototyping is the real world scale (that of the knitted material). In this context, Knitted Heat can be described as an expressive prototyping tool presented in real world scale.

re-texturizing

Structure 4 is an open knitted design that when placed in a 3D modeling context, allows the designer to play with the placement or scale of the pattern on the desired shape of the garment or object (Fig. 11). Through tactile interaction Structure 4 is able to express various types of patterns—opening possibilities for multiple relations in between its texture and form.

On the right side, Structure 4 is a plain knitted surface. The conductive yarns are placed in fine layers on the wrong side to produce a transformation on the plain knitted side via heat. Depending on the location of touch and how the fingers are placed on the material the conductive yarn creates various types of tactile patterns on the right side of the material.

re-shaping

The knitted surface as in Structure 2 is shaped by...
Due to heat and tactile interaction, the soft textile surfaces can change properties by stiffening. According to which conductive lines are pressed and how much the hands are pressing the material and on which areas, its surface can be three dimensionally shaped by varying its softness. The textile material in this example is seen as a means to transform a soft surface into hard shape and to explore them simultaneously by physical manipulation of the material.

re-scaling

Relating the experiments with heat patterns to larger scales of design, such as architectural design, various relations based on the relation between visual and tactile patterns can be created. The experiments with heat patterns expose the potential for new tactile expressions in space design. The textile surface in Structure 5 has a static visual pattern that relates to the dimension of space design. The textile s urface in Structure 5 has a patterns expose the potential for new tactile expressions in the context of interactive materials, providing open expressive tools for further designs, since textiles act as materials by and for design. The examples indicate how the interactive tactile surfaces can complement the digital tools of prototyping by material exploration at real world scale, bridging new relationships between CAD applications and the concreteness of textile materiality.

By questioning the relation between human interaction and surface exploration in the design process of form making, Knitted Heat presents multidimensional forms that can be further transformed by the designer in form, texture, interaction, etc. This offers a new perspective in the context of interactive materials, providing open expressive tools for further designs, since textiles act as materials by and for design. The examples indicate various ways of exploring the surface’s textural effects at different scales in the initial stages of prototyping, while retaining the textile as reference dimension.

The role of an interactive material for design, in this context, is to integrate various design processes leaving certain aspects open-ended for further experimentation with the textile texture.

By proposing alternatives to shaping, texturizing and scaling we aim to question the textile role in the design process for various fields and engage new dialogues where the textile and interaction can materialize design thinking. Consequently, the textile becomes both a tool and a material for design blurring clear distinctions in between material by design and for design; where the basic variables of design bridge various steps in the design process from material “fabrication, application and appreciation” (Doordan, 2003).

DESIGNING WITH INTERACTIVE TEXTILE EXPRESSIONS

Adding sensing and reacting properties to a textile extends its expressive possibilities and brings new challenges to the area of textile design. The relation between the textile material and the interaction can be seen as interactive textile expressions. A textile’s interactive expressions should be seen or experienced in a textile over a period of time; they are both spatial and temporal in their nature (cf. Hallnäs and Redström, 2006, 2008). For example, examples of interactive textile expressions in the Knitted Heat collection are those of shrinkage, breakage and stiffening. The collection also shows examples of expressions that are purely tactile and in the form of temperature changes (as heat).

The two collections were designed with a focus on their interactive expressions, and are meant to exemplify ways of designing with these materials. They are meant to show the potential of how to reflect upon and understand the expressional tools these kinds of constructions and materials provide. This is made by both envisioning specific designs but also by opening up the design process to create new designs that use the same interactive expressions with another scenario. A specific design example exemplifies one way of interacting with the textiles (as an example, see Structure 3). The scenario described is simple. Still, multiple choices have been made when designing this specific interactive expression. In this way, the design examples allow for further designs with the same materials (Fig. 15).

The specific example breaks in one area. The breakage occurs after 1 touch the textile, and is sustained for 15 seconds. The resulting expression is clear.

For further design, we can ask ourselves:

- When touching the textile, where should it break
  - On several areas or one area
  - On the opposite side from where I touch or on the same spot
  - As a whole stripe or as a part of a stripe
  - Etc.

- When touching the textile, how should it break
  - Fast or slow
  - In a subtle or clear way
  - In a small or big area
  - Etc.

- When touching the textile, when should it break
  - Directly or with a delay
  - Once, or as a chain reaction
  - As long as I touch it or within a range of time
  - Etc.

All issues above are part of an interactive textile design and cannot be ignored. While issues considering how and where the textile should break are closely related to the material design, issues considering when to break are more related to the design of the computer program. The material design (the textile design, choice of yarn, electronic design etc.) and the design of the computer program function together and cannot be overlooked.

INTERACTIVE TEXTILES BY/FOR DESIGN

Through our design explorations, we were able to define knitted expressions for surface transformation on shrinking, breaking, stiffening, texturizing and warming when textile and interaction design form a common ground.

Describing design scenarios relating human interaction to surface exploration in the design process of form making, or extending the textural expressive registers of architectural space design with tactile patterns, we aimed to initiate new questions on textile materiality when placing Knitted Heat in the context of materials for design.

The design scenarios illustrate potentialities in a design space where the textile material is placed as a generative tool for new processes and expressions; a potential design space where textile materiality give computation a tangible dimension in the design process. Therefore the concept of interactive textiles for design uses the effects of heat as a prototyping method for object shaping or as a medium for interaction in the architectural space.
REFERENCES
Abstract: This article presents three scenarios in which we explore different possibilities for interactive textile hangings, textile hangings that are knitted and attached to servomotors. We have identified a series of variables that address the relationship between the expressions of the changeable pattern, created by rotating motors, and the unchangeable textile pattern. We use these variables, combined with contextual dichotomies, to discuss the relationships between the textile expression, the temporal expression, the place and the interactions for these scenarios.

Keywords: Interactive surfaces, textile design, expressions of movement, space, interaction design
Textiles are often used to affect a room. Textile wall hangings, for instance, draw on a long tradition of decoration and story-telling where images are expressed in a textile language of interlaced yarns and colours (Albers, 1993). Alongside their aesthetic value textile hangings can also have functional purposes, e.g. to insulate or to improve acoustics. We find the notion of textile hangings interesting because they give a sense of lived-in space. Their long history makes them recognisable in numerous contexts and they balance aesthetic and functionality in a way that makes them open to new interpretations. Moreover, by combining textile hangings with temporality - similar to that found in music or soundscapes (e.g. the use of music to catalyse shopping in supermarkets) - we are able to work with expressions that evolve over time – temporal expressions that can give a sense of a living and lived-in space.

In this project we want to explore the potential of interactive textile hangings. In particular, the role these textiles in giving a space a sense of belonging, connection or even meaning (Cf. Certeau, 1984; Augé, 1995; Dant, 2005). Others have worked with interactive textile hangings or textile façades but from different perspectives. Slow Furl, for instance, is a project by Mette Ramsgaard Thomsen (2009) where she explores the use of textile logic in an architectural construction as well as the temporal dimension of architecture in movement. The 100 Electrotextiles Arts Years by Maggie Orth, on the other hand, explores the limitation of the technology used to create a temporal expression in the textile, here thermo chromic ink (Orth, 2009).

A challenge in this project lies in achieving synergies between the textile expression, the temporal expression, the context, and the interaction. Bengtström et al. have treated this challenge as a matter of designing with ‘becoming materials’: “the term is employed to indicate both the material attribute of changeability within a given context and the continuous negotiation of the material expression directly or indirectly with the contextual factors in which it comes to be” (Bengtström et al, 2010, p.158). We approach the interaction design task as a matter of developing expressions since “function resides in the expression of things” (Hallnäs & Redström, 2006, p.166). From the outset the material setup comprises knitted textiles and servomotors controlled by a computer, with various types of sensor input. We develop and explore textile structures, patterns, and scales in relation to the motors’ movements and positions, and to possible contexts and interactions.

This article is an analysis of work-in-progress. It sheds some light on the interplay of these aspects. We show how together they contribute to insights that open up the design space and take the textile expression, interaction, or context in different directions. We exemplify the interplay through three different scenarios of interactive textile hangings.

To develop an understanding of the expression possibilities in the combination of servomotors and textile surfaces we set up a series of explorations. The initial set-up consisted of up to 16 servomotors mounted to different surfaces. They were controlled from an Arduino board and, through a graphical interface made in max/msp, we could easily change the programme. We interlaced yarns and colours (Albers, 1993). For the textile setup, we aimed to combine textile hangings with temporality - similar to that found in music or soundscapes (e.g. the use of music to catalyse shopping in supermarkets) - we are able to work with expressions that evolve over time – temporal expressions that can give a sense of a living and lived-in space.

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**The Textile**

To develop an understanding of the expression possibilities in the combination of servomotors and textile surfaces we set up a series of explorations. The initial set-up consisted of up to 16 servomotors mounted to different surfaces. They were controlled from an Arduino board and, through a graphical interface made in max/msp, we could easily change the programme on the Arduino board and thus explore different expressions.

Beginning with some simple knitted textiles we gradually designed and tested a series of knitted geometric patterns at different scales. Through this process, we found different expression qualities - each with potential for different interactions and contexts. At the same time, as our ideas of interactions and contexts evolved they influenced the design of the
textiles and the motor positions and movement. Through design exploration, we were able to identify different variables having an impact on the overall expression. The variables address the relationship between the knitted expression (i.e. the scale, shape, and direction of the pattern and the density, elasticity, and weight of the material) and its expression when exposed to the pattern of the motors' movement (i.e. their positions on the surface, the direction, the speed, and the angle of rotations). They are described here as dichotomies of textile expressions to show the span of possibilities. Or, illustrated through three basic design questions:

What is the relationship between the knitted pattern and the movement pattern?

In what way does the pattern of the motors affect the surface texture?

How is the direction of movement expressed by the knitted pattern design?

Dominant movement pattern - The textile is knitted on a circular knitting machine. The knitted pattern is small scale and the material is extremely elastic and dense. The motors are placed in a regular grid at a scale larger than the knitted pattern. The pattern created by the motors' rotations overshadow the knitted pattern, thus the motor pattern is the dominant one.

Dominant textile pattern - The textile is a structural knit made on flat knitting machine. The scale of the knitted pattern is large and the pattern is strictly structured. The construction of the material makes it highly elastic. The pattern created by the motors' rotations (in opposite directions) produces only minor changes in the textile expression. The movement pattern is subordinate to the textile pattern.

Arrangement: Regularity in the Temporal Textile Expression

Irregular movement pattern - The textile is knitted in a structural geometric pattern. The motors are placed in a grid but their movements are uncoordinated and in opposite directions. The motor pattern distorts the knitted pattern and makes it appear in an irregular way.

Regular movement pattern - The textile is knitted in a regular pattern. The motors are placed in a grid and rotated in the same direction. The movement pattern is carefully positioned in relation to the knitted pattern. The motor pattern emphasises the regularity of the textile pattern.

Direction: Movement and Textile Working Together or Opposing

Figure 3. An irregular movement pattern in both time and space.

Figure 4. A regular movement pattern in both time and space.

Figure 5. The textile and movements are working together.
Together - The textile is a complex geometric knitted structure. When stretching the textile surface in a vertical direction the visible shapes initially separate and reveal the coloured stripes. By letting the motors perform this stretch they work together with the textile structure and form an intentional and predictable pattern.

In conflict - The knitted textile is the same as above. However, the motor is positioned to rotate against the textile pattern. The result of this combination is a rather unpredictable pattern.

To illustrate the contextual dimension of the design space for the interactive textile hanging we articulated a series of dichotomies. Each denotes different spans of contextual variables that would be interesting to explore: picture frame scale v. façade scale; private v. public; ceremonial v. informal; co-located v. over a distance; individual v. collective interaction; and immediate v. delayed response. They have formed our common vocabulary for discussing the development of the contextual qualities of the textile expression.
While exploring the potential of different materials and motor positions, we discussed which context to have as a frame of reference. Our choice was made from an interest of exploring certain interactions and spatial dimensions in relation to our material explorations. After an initial discussion of the dichotomies we visited four places: a hotel room (small place which is private yet impersonal, over a distance), an elderly home (a home away from home where you might spend years), a chapel (with a ceremonial and solemn atmosphere), and a mall (a large scale public place bordering on impersonal and mundane). We then discussed the differences and possible qualities of these places. For instance, in the hotel room you are often separated from the ones you know. It is a sort of non-place, private for a while but not at all personal (c.f. Augé, 1995). The elderly home, on the other hand, can often be the last place where you might live, without relatives. Your acquaintances might pass away. The chapel is a place where we say farewell to the dead, yet we cannot communicate with them. It might be an introverted action, yet shared with others. We chose the chapel.

Even though we had limited our design space through the choice of simple, small servomotors it was clear that the position of the motors - their direction, angle, and speed - in combination with the shape, scale, elasticity, and density of the textile could be combined and designed with very different results, in terms of expression. Furthermore, these expressions could appear differently depending on the scale, the societal setting and the activities of the place and how people might interact. Through our exploration, we envisaged a couple different directions in which expression and interaction could be coupled. To bring out these different directions – to not confuse them with differences due to context or activity etc. – we found it suitable to phrase three scenarios in the same context, i.e. the chapel.

Choosing a Place

Three Scenarios

Surface Distortion Message

The Textile

The textile veil extends in the central area of the space. The lightness of the textile softens the space. Its white translucent surface has no texture. The only texture that appears to viewers are fine, irregular folds that fall down to the pavement.

The Scale

Figure 13. Rendering of the textile in context.
The Scale

Figure 14. Rendering of textile in context.

The Interaction

The chapel, a funeral

We enter the room.

Behind us. Light from the outside filters through the openings of the textile.

The amount of light varies.

There is a moment when we haven't decided yet where to take a seat.

We move around a bit, nodding, saying a few things to each other.

Then we take the seats.

We are still.

The light from behind us reduces and rests still.

There is sound, but we are still.

There is activity, but we sit still.

At one point we stand up and take a few steps, one or two or three by three.

Then return to our seats. Light from the rear glisters slightly and disappears.

Sound. We all stand up and sit down.

Sound. We all stand up, walk towards and away from each other and out.

The Textile

Curled stripes of knit are placed to form a path. The irregularity of the stiff and curled lines of the knit forms a continuous surface. Gentle winds continuously reposition the edges. The regular texture orders the overall expression in a closer view.

The Textile

Curled stripes of knit are placed to form a path. The irregularity of the stiff and curled lines of the knit forms a continuous surface. Gentle winds continuously reposition the edges. The regular texture orders the overall expression in a closer view.

The Movement

Our movements are reflected in the textile surface.

The textile is still when we are still. The textile is still when there is sound if we are still.

The textile is moving when we move. The textile answers to our steps. Patterns start to reorder. When we find our seats and stand up. With an increased intensity if we all move at the same time. Limited intensity if we are only few or move less.

When the textile is moving, patterns are revealed and concealed. Structures are formed and reformed. The surface will open up for light and then close, opening up other parts.

Affected by the collective.

The textile movement is one unit, with more or less.

A slow billowing surface.

Striped Turn Seed

The Textile

Curled stripes of knit are placed to form a path. The irregularity of the stiff and curled lines of the knit forms a continuous surface. Gentle winds continuously reposition the edges. The regular texture orders the overall expression in a closer view.

The Scale

Figure 15. Rendering of textile in context.

The Interaction

The chapel or similar nondenominational space

He enters the room.

To sit down for some time.

He is there as a way of thinking of someone.

Thinking.

Not thinking.

He does whatever he does there.

You are at a different place.

Between trees.

Walking.

At one place fifteen textile segments are lined up. Together they create a wall.

A sudden change.

Different movements in all of the segments. Spreading down and up and to the sides.

The movement quickly opens up the wall and keeps it open for a few seconds. Opens up for the wind and you see through the wall.
You hear through the wall.
The leaves of last season.
A person's steps in the grain.
Then they slowly turn back to flat.
You know what created the change.

The movement
A twist.
The surface changes, the knitted lines start to bend.
The segment turns quickly in different directions.
Slows down before reaching its limit.
From order to disorder, from randomness to structure, the stripes reconfigure continuously in three-dimensional patterns.
Then the stripes go back with slow shifts.
To rest in their initial position.
Reconstruct the flat surface again.

Discussion

In the first scenario, surface distortion message, the textile is positioned in the central parts of the chapel. It will always be the background or foreground of the activities taking place. The movements, winding and unwinding, must be subtle enough to work in that setting, and yet strong enough to contribute something. We see the lack of texture and the irregularity in the arrangement of the movement expression as a way of doing this.

Moreover, the plainness of this textile provides the possibility of creating different, distinct changes of movement, which the interaction scenario requires. The movement can start at different places, spreading in different directions, and with different intensity, depending on the length, and content of the messages etc. The textile is predictable when it comes to types of change, but unpredictable when it comes to where the movement will happen.

In the first scenario the movement pattern is clearly always dominant to the textile pattern, which is necessary for the interaction and context of the textile. In the second scenario, light filter movement mirror, the movement pattern is less dominant than the textile pattern. The textile is made up of repeated segments with a clear structure. The segments are parted and joined by the motor movements, but the movements will not take over the textile pattern as much as in the first scenario. Both the textile and the movement pattern are regular which is directly reflected in the interaction and placement. This textile hanging is positioned as a light filter and is affected by the collective interaction of our movements. We have it behind us during the ceremony. It will be still when we are still but let the light fluctuate when we move, with corresponding intensity. Standing in the cloakroom it will spread the expression of the ceremony.

The last scenario, striped turn seed, is not co-located in the sense that interaction is only over a distance. Since the motors are attached to the fabric in another direction, each motor affects a much larger surface area than in the other scenarios. The larger scale of movement over a distance. Since the motors are attached to the fabric in another direction, each motor with corresponding intensity. Standing in the cloakroom it will spread the expression of the ceremony.

There is a similarity in the first and last scenario. Both play with how the thought of someone can affect a textile surface positioned elsewhere. The difference is that in the first scenario you make a very conscious act of sending a text message. It is not important whether someone sees the change in the textile surface or not. It is just important for you, as the sender, that you can do something that will be substantiated somehow and that you can be in your thought. In the last scenario, where a "speed" is planted, i.e. the person triggering the turning of the stripes, might be unaware or indifferent to the additional consequences of their actions. It is the viewer's perspective that is interesting. What it might occasion when we are somewhere else. These differences in interaction are also reflected in the differences of the textile movements. As already mentioned, the first scenario is limited in intensity whereas the last scenario has increased intensity. The first does not change much in three dimensions whereas the last does, etc. It is also reflected in their positions. The first scenario has its value in its location and privacy. The last scenario is loud, placed outdoors in public.

We have been discussing scenarios from different perspectives. Some remarks are from an expression point of view, others from the interaction point of view, and some remarks relate to how expression and interaction are coupled together. In our own discussions with each other we saw the need to be able to describe certain differences between what each of us had seen so far. The textile expressions developed describe specific dynamic surface designs; they define basic textile expressions as a design language of movement that we used when designing the scenarios.

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Repetition: interactive expressions of pattern translation
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Abstract
As a way of opening a space where methods from the fields of fashion design, textile design
and interaction design overlap, the project Repetition intersects different methodologies
through practice-based research in design. Experiments were conducted to explore ways of
creating relationships between body and space by means of translating information as
pattern design between garments and interactive knitted walls. By arranging a startup
performance, we reflected on the expressional variables that influence the expression of the
pattern translations; variables concerning the garments, the walls, the print and the
movements were illustrated by the expressions found. The result formulates specific
descriptions regarding accuracy and distribution of pattern translation, illustrating basic
concepts of pattern formations identified in visual changes appearing in the garment. By
communicating our understanding of basic expressions, Repetition aims to formulate a new
framework for collaborative work as a method for further design.

KEYWORDS: textiles, fashion, interaction, design methodology

Introduction
Two decades have passed since the first approaches were made toward combining clothes
and technology through the concept of wearable computing (Mann, 1997), where body-worn
computers, including devices such as cameras and sensors, were placed directly on the body
to provide its wearer with an augmented reality that allowed him/her to interact with the
surroundings (Starner, et al., 1997). Since then, developments in technology and textile
materials have pushed design fields such as textile design, fashion design and interaction
design toward development of novel processes and methods to explore both functional uses
and means of artistic expression.
In various ways, research projects explore technology as a means to create new social or spatial relations through the changes the garments materialize; they bring into view different visions on how technology can be integrated directly with fashion to introduce new expressions in wearing or to influence the ways in which one can express herself through the garments by wearing them.

*The Fine Jut Dress* (Post, et al., 2000) may have been one of the first examples of expressive reactive garments including small technological devices, such as light emitting diodes, which react to the wearers’ body movements by lighting up. Several examples of garments able to react and respond have since been developed, presenting new conceptual ideas that interact with their wearers but also with their surroundings (cf. Seymour, 2010).

Using body-to-body interaction as a method of communication, examples of garments able to communicate a history of use through a physical memory are the garments created within the *Memories rich clothing* project (Berzowska, 2005). The collection includes a shirt that is able to sense and display physical contact, as a hidden microphone and touch sensors detect whispered sounds and physical contact. Other examples of narrative garments are those created in the *E-motion* project at the Berlin University of the Arts, including a low-tech trench coat that allows people to communicate by writing messages on its back, functioning as an analog message board (E-motion, 2009). In *Raeth* (Jacobs, Worbin, 2005), dynamic textile patterns are integrated in wearable everyday objects investigating personal ways of expressing one’s personality in public spaces. By exploring social interactions through the dynamic objects, the project designs new ways to connect people as a method to propose new forms of social interaction.

*Costumes* (Bondesson et al. 2009) explores the relationship between body and space through the expressiveness of interactive textiles. In the context of a performance, body movements affect the visual expression of a room by changing colours and through that, affecting patterns. Accordingly, the movements of three dancers wearing interactive dresses affect the colour of a tapestry via radio signals. The way in which movements have been choreographed and are expressed by the dancers affects the changes in the visual expression of space.

As an example of practice-based research in design, this paper presents *Repetition*. *Repetition* is an experimental project meant to explore relationships between body and space as a method of creating interactive repetitions of patterns using body movements. In *Repetition*, the body and space are exchanging tactile and visual information through movement. In contrast to *Costumes*, the texture of the space affects the changes in the pattern of the garments on the body through near-field interaction. By sensing and reacting to the proximity of a body, the space is able to leave marks/patterns on the garments as a form of temporal expression. Our research explores how technology integrated in a space can affect the expressions in wearing. Interactive walls are designed to incorporate the electronics; they sense and react to tactile interaction with the body. Sensitive garments are designed to change their patterns according to the movement of the body in the space.

The project opens a space where methods from fashion design, interaction design and textile design overlap. By intersecting different design methodologies in the experiments, this project aims to build a framework for collaborative work.

**Method: Exploring by Design**

In order to bridge relationships between body and space, dynamic patterns were formed and explored. The experiments searched for ways of creating relationships between body and space by means of translating information as pattern design. In the experiments, we explored ways of visualizing these relationships in the form of garments with the ability to alter their patterns.

Two interactive knitted walls and several responsive garments composed the setting (figure 1). In a performance, a dancer was asked to connect the elements of the setting, e.g. the walls and the garments, in repetitive movements.

*Figure 1 shows the elements of the setting.*

Thermochromic printed garments reacted to the heat emitted by the knitted structures, which made up the textured surface of the walls; when put together, they formed a system for exchanging patterns between body and space able to take on interactive expressions. The surface of the garments was reactive: its ability to exhibit the visual transformations through changing of colours and shapes were possible due to thermochromic paste being printed on the garments.

Walls

Soft textile walls were constructed to display interactive heat patterns in the shapes of looped lines and squares. Each conductive line was programmed to heat up when in contact with the body. When the body pressed the conductive patterns, the walls responded (Dumitrescu, Persson, 2011). The patterns of the wall translated their shapes onto the thermochromic garments, reforming shapes and arrangements of patterns depending on the placement of the body and its interaction with the wall. The intensity of the heat pattern depended i.e. on how long the body was in contact with the wall and for how long it stayed away from the walls. Two distinct knitted structures were designed to explore i.e. how the texture of the wall influenced the appearance of the pattern on the garments.
The first structure was designed using an inlay knitting technique (figure 2). The structure was loosely knit to create a fine net of conductive threads. In this example, the transformable pattern of the surface was designed as interactive stripes of heat. The rows of conductive yarns act both as sensors and actuators. The principle behind the sensing technique was proximity sensors.

Once the conductive yarns were touched, the affected area was programmed to heat up after 10 seconds. The striped repeats of heat could also be programmed to react at different time intervals. Each row of conductive yarns was able to have a different repeat time, allowing each row to be programmed to have a distinct temperature. Accordingly, when the body came in contact with the conductive lines, a varying amount of heat were activated and sensed.

The second structure combined a ridge pattern with a full rib (figure 3). The textile background was of a dense structure. The surface was compact and elastic to enhance the three-dimensional texture of the conductive ridges. The ridges formed a robust pattern with dense rows. Similar to the first structure, the rows of conductive yarns were planned to be both sensors and actuators and they responded by activating formations that were each made up by two shapes at distinct intervals of time. The transformable texture of the surface depends on the area touched. When the body came in contact with the textile surface, heating is activated for that specific area. If the body remained in contact with the wall for a longer period of time, the heat pattern activated two other shapes in a position near to that of the first formation and in doing so, repositioning the heat pattern on the garments.

For both structures, sequencing was an essential part in the pattern design as it decided the accuracy and placement of the pattern translation from the wall to the garment.

Garments

A series of garments were designed in fabrics printed with thermochromic ink. Designed under the theme repetition, the garments emphasized the theme as repetitions of the shapes and the patterns. During the design process, it was important to have a connection to the wall; the movements of the body toward and away the wall became the starting point of the search for the shape of the first garment (figure 4, 5, 6). Although we soon realized there are not that many ways in which to interact naturally with a wall, this made us only more curious to continue the exploration. Different shapes were explored and tested, starting from interaction with the wall (figure 7). Shapes inviting the wearer to interact with the wall in specific ways were in focus.

Photographing, draping and sketching alternated in the design process and the utilization of these methods aimed to explore the repeated feeling in the garments, i.e. in the shape and the pattern of the fabric. After draping different details and silhouettes, pleats were integrated in the garments as a reference to the repetition theme. This process of finding shapes for the garments was repeated for the following designs: the pleats and the shape shared a common origin, but were not exact copies of the first garment. Before deciding on the final expression of the garment, the dancer tried the toils and gave feedback about the
shape and the ability to move in the garments, e.g., comments on the length and width of parts of the garments to better facilitate movements of the leg up against the wall and adjustments on the pleats (Figure 8). Later, some adjustments were made to the shape of the final designs.

Fig. 5 shows images from the sketching process of the garments.

Fig. 6 shows images with the garments used in the performance.

Fig. 7 shows images during the design process while sketching the wall interaction, the garments' shape and the position of print.

Fig. 8 shows images with the ballet dancer testing the garment.
Prints

When designing with thermochromic ink, there are some basic aspects to consider in the process, i.e. the properties of the material and the print. Experiments were made with different fabrics such as cotton and wool, testing different thicknesses. Due to the fact that thermochromic print stiffens textile surfaces, we searched for ways of balancing the garment design with the expression of the print itself. We also had to perform tests to find out the duration of the visible effect caused by the heat on the different materials (figure 9, 10). The experiments showed that the wool fabric retained heat the longest. The heat pattern kept its translated expression longer and, thus, wool became our first choice of material for the garments. We also tested different colour combinations in order to find out whether the expression of the heat pattern appeared clearly. We searched for contrasting combinations in order to make the changes in the patterns visible from a distance.

The choice fell on screen-printing as the printing method for the thermochromic ink. Consequently, we decided to use the printing frame as a method for creating patterns on the fabric; it also related to the theme of repetition. The shape of the frame created a repeated pattern on the fabric.

Figure 9 shows print tests with different colour combinations: violet/pink.

Figure 10 shows print tests with different colour combinations: green/cyan.

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Figure 11 shows the position of the printed pattern on the fabric.

The expression of the printed garments is described as structured because of the horizontal and vertical lines created by the printing frames (figure 11). The lines of the patterns on the fabric reinforced the expression of the vertical pleats. The checked pattern on the fabric was formed by dark lines and squares and their expression became strong in the overall garment design.

Movement

To be able to achieve the effect on the garment, all the elements of the set had to combine: the performer had to move in a loop, moving toward and away from the wall to create, translate and repeat patterns overlapping all the design dimensions, e.g. the wall, the garment, the space, the motions. The garments moved with the performer and the shape of the garment changed as the dancer moved (figure 12). The movement of the performer was one of the crucial elements for the expression in wearing and how we experienced the final result. This is also what needs further development in next phase of the project.
The design process started by arranging an initial performance, i.e. taking a holistic view on the project. In this phase, we focused on understanding the expressive value of the formal variables that influence design decisions. We reflected upon the essential relationships that define the overlaps of the design spaces.

The shapes of the garments defined the movement of the body and, thus, the possible positions in relation to the wall. The garments invited the performer to move in a certain way; the way the body moved in space defined the placement, the shape and the depth of the emerging patterns on the garments. Relating different designs in this way, temporal pattern expressions were formed and repeated as a performance in space. The temporal pattern on the garment is a trace of repetition the performer attempts to perform. The dancers were given a single word to perform: “repeat”. They improvised repetitive motions. Subsequently, their actions in contact with and away from the wall began leaving repetitive patterns on the garment’s surface; their looped movements added another dimension to the design of the garments, reinforcing our theme: “Repetition”.

This initial setup worked as a platform and framework for our experiments with the body, the garments and their interaction with the textile wall (figure 13). In doing so, we aimed to map how all the design variables were put together and find out how they related to the results. We reflected upon how the body and the movements effected the changes in the expression of the garments, not only by drawing temporal patterns on the surface but also the way in which the shapes of the pattern were effected. In this first experiment, we searched for ways of enhancing the visibility of the temporal pattern on the garments and the project focused on finding ways of describing and emphasizing these expressions.
Reflections on the design: methods and expressions of pattern translation

Methods: formal variables for the pattern translations
In the design process, the following formal variables regarding the walls, the garments the prints and the movements for pattern translations were identified:

<table>
<thead>
<tr>
<th>Walls</th>
<th>Garments</th>
</tr>
</thead>
<tbody>
<tr>
<td>knitted pattern</td>
<td>shape</td>
</tr>
<tr>
<td>heat pattern</td>
<td>print</td>
</tr>
<tr>
<td>timing</td>
<td>material</td>
</tr>
<tr>
<td>temperature</td>
<td>movement</td>
</tr>
</tbody>
</table>

In *Repetition*, the movement of the dancer is a relational element that allows the pattern expression to connect walls and garments. Thus, the changing expressions of the garments are dependent on the knitting design of the walls (*timing* - programmed activation time sequence for the heat pattern, *knitted pattern* - shape made by the conductive threads, *heat pattern* - area heated when activated, *temperature* - intensity of the heat pattern) and the way in which the body interfaces movements, i.e. relating walls and garments.

The way movement design is defined by the dancer depends on the *timing* - the time sequence when the body is/is not in contact with the wall, *shape* - the way the body shapes itself to the wall, *recurrence* - how movements are repeated. Accordingly, the shape of the garment influences the movements of the body and the interaction with the wall.

The movement of the walls translates to the clothes is dependent on movement variables materialized through colour changes on the surface of the clothes. The expression of the colour changes on the garments also depends on the textile variables (*material* - thermal conductivity, *density* of the structure, *print* - thickness of the printed layer, contrast of printed colours). The surface of the garment reacts when the body comes into contact with the wall and, thus, the way in which the variables of the wall form the heat design and the way in which the interaction is formed by movement combine with the textile in redefining the final surface expression of the garment.

The changing expression of the body in relation to the knitting design could be described in terms of *accuracy* and *distribution* of the surface of the clothes. Accuracy of the pattern translation describes the precision of the shape rendering of the walls on the garments through body movement. Distribution of the pattern translation describes the way the texture of the wall is repeated on the garments through body movement. The following examples show specific expressions of *accuracy* and *distribution*.

Expressions of pattern translations
When designing a printed pattern, the shape and the way it is repeated are basic formal variables to be considered in the pattern forming process. The expressions of pattern translations add formal variables to those of a traditional printed pattern such as time, interaction, texture of the wall, movement of the body or shape and placement of the garment in space. The result focuses on describing some of the ways the wall pattern translates its texture on the garment, by the movement of the body in space. We will start by describing formal aspects of basic design variables such as shape and repetition. The emerging expressions describe the *accuracy* of the pattern translation and the way the *repetition* is distributed on the garment because of the movement of the body in relation to the wall. The expressions, e.g. *reflected*, *diffused*, *mirrored*, *superimposed*, define ways of designing pattern translations through body interaction in space: they describe the way the visual transformation is manifested as patterns on the garment.

Def. *Accuracy* of the pattern translation describes the precision of the shape rendering of the walls on the garments through body movement. The expressions can be reflected or diffused. A *reflected* expression translates the pattern of the wall to an identical shape on the garments through body movements. A *diffused* expression translates the pattern of the wall to an indefinite shape on the garments through body movements.

**Reflected**
Example 1.
Fine lines of conductive yarns formed the knitted pattern on the wall. The garment was made out of light wool. The performer placed her back on the wall so that the backside of the garment came in contact with the wall. The heat pattern on the wall was immediately activated one knitted stripe as the body pressed the garment against the conductive lines. The emitting temperature was low. The body kept this position for a short time and then moved swiftly away from the wall. The duration of the interaction and the heat exposure were equally short (10 seconds). The pattern on the wall was translated with clear lines to form an identical shape as colour changes became visible on the garment (figure 14).

**Example 2.**
Robust ridges of conductive yarns formed the knitted pattern on the wall. The garment was made out of heavy wool. The dancer placed her front side on the wall, heavily enough to support his/her body on it, and the front area of the garment came in contact with the wall. The heat pattern on the wall activated as the body pressed the garment against the conductive lines at an interval of 10 seconds. The emitted temperature was higher compared...
to the previous example due to the heavy wool in the garments. The body maintained this position for a while, allowing the garment to be exposed to heat long enough to translate with accuracy the outline of the knitted pattern onto the garment. The knitted lines of the wall were translated to form an identical shape as colour changes became visible on the surface of the garment (figure 15).

Example 3

a. overexposure

Fine lines of conductive yarns formed the knitted pattern on the wall. The garment was made out of heavy wool. The body was placed so that the back of the garment came into contact with the wall. The heat pattern on the wall activated as the body pressed the garments against the conductive lines. The emitted temperature was high. The body stayed still, maintaining the same position. The time of exposure was long for the printed wool, exceeding 30 seconds. The knitted lines of the wall dispersed a constant amount of heat to the garment, influencing larger areas. When the body moved away from the wall, the colour changes became visible on the garment in the form of distorted shapes (figure 16).

Figure 15 shows the reflection of the pattern on the garment.

Example

b. underexposure

Fine lines of conductive yarns formed the knitted pattern on the wall. The garment was made out of heavy wool. The body touched the wall briefly. The heat pattern on the wall activated some of the stripes as the body pressed the garment against the conductive lines. The emitted temperature was high. The time of exposure was less than 10 seconds, which made it difficult for the pattern to be clearly translated to the garments. The knitted lines of the wall dispersed an irregular amount of heat over the garment and merely influenced certain areas. When the body moved away from the wall, the colour changes became visible on the garment as interrupted lines (figure 17).

Figure 16 shows the diffusion of the pattern on the garment.

Figure 17 shows the diffusion of the pattern on the garment.
Def. Distribution of the pattern translation describes the way the texture of the wall is repeated on the garments through body movement. Distribution can be superimposed or mirrored. A superimposed expression translates through movement the texture of the wall by overlapping the layer patterns on one side of garment. A mirrored expression translates through movement the texture of the wall on both sides of the garment.

Superimposed
Example 4
a. parallel
Fine lines of conductive yarns formed the knitted pattern on the wall. The front side of the garment was placed against the wall. The heat pattern on the wall activated one of the conductive lines as the body pressed the garment against the wall. The temperature of the pattern was equally distributed over the knitted lines for an interval of 30 seconds. The body stayed still for 20 seconds during the first exposure. Keeping the same orientation toward the wall, the body began to move up and down at short intervals; the body pressed against the same area of the wall by changing its position on the vertical axis at different time intervals.

When the body moved away from the wall, the colour changes became visible on the front side of the garment. The patterns translated showed the regular repetition of the texture of the wall in different positions on the garment. The texture of the wall was overlaid on the same area with the striped patterns in parallel positions (figure 18).

b. rotated
Fine lines of conductive yarns formed the knitted pattern on the wall. The body was placed so that the backside of the garment maintained a twisted position in contact with the wall. The translated lines on the garment had a random direction compared to the horizontal stripes of the wall. The heat pattern on the wall activated for several of the conductive lines as the body pressed the garment against the wall. The temperature of the pattern was equally distributed over the knitted lines for an interval of 30 seconds. The body stayed still, pressing the garment against the wall, providing 20 seconds of exposure. The body then twisted rapidly to the other side of the wall, exposing the backside of the garment for an equal amount of time as that of the first action. The colour changes became visible on the front side of the garment and started to grow on the backside. By allowing both sides to come into contact with the wall, the patterns translated were mirrored as a regular repetition of the wall texture on the garment. As the dancer moved away from the wall, the pattern became visible on both sides. The garment translated the pattern from the wall and distributed it all around its own shape (figure 20).

Figure 18 shows a parallel superimposition of the pattern on the garment.

Figure 19 shows a rotated superimposition of the pattern on the garment.

Mirrored
Example 5
Fine lines of conductive yarns formed the knitted pattern on the wall. The garment was made out of heavy wool. The body was placed so that the front side of the garment came into contact with the wall. The heat pattern on the wall activated several of the conductive lines as the body pressed the garment against the wall. The temperature of the pattern was equally distributed over the knitted lines for an interval of 30 seconds. The body stayed still, pressing the garment against the wall, providing 20 seconds of exposure. The body then twisted rapidly to the other side of the wall, exposing the backside of the garment for an equal amount of time as that of the first action. The colour changes became visible on the front side of the garment and started to grow on the backside. By allowing both sides to come into contact with the wall, the patterns translated were mirrored as a regular repetition of the wall texture on the garment. As the dancer moved away from the wall, the pattern became visible on both sides. The garment translated the pattern from the wall and distributed it all around its own shape (figure 20).
Dissemination: reflections on experimentation as method for practise-based research in design

One way of discussing experimental research in design is through the perspective of the new knowledge formulated to develop the methodology of the field, i.e. seeing practice as the main contributor to the understanding of the artistic potential brought about by new means of expression, e.g. materials, techniques, methods (c.f. Biggs, 2002; Frayling, 1993). Accordingly, the results describe the expressions found in the design and the materials explored (c.f. Hallnäs, 2010). They aim to reduce a complex process to an abstract explanation as a method for advancing knowledge when dealing with new design materials and, by doing so, intend to create a new foundation for the design field.

The performance in Reptition acted as an initial start up: it framed essential questions for the design, i.e. how different variables, e.g. the textiles, the shape of the garment, or wall interaction, relate in the pattern expressions. We explored ways of illustrating these relations in the practical work. The design experiments in this practice-based research project functioned as ways of reflecting on the methods used. During work on the setup for Reptition, we interpreted the experiments not as finished designs but as design explorations.

In Reptition, the experiments aimed at finding new ways of creating relationships between body and space by means of translating information as pattern design. Bridging relationships between body and space, dynamic patterns were formed and explored as a method of connecting design variables from fashion design, textile design and interaction design. In our explorations, we combined new materials and existing design methods from different fields to be able to formulate a new framework. The concept of pattern translations played a central role in the experiments: it aimed to open a dialogue between the design disciplines involved in the project and further reflections as foundations for a new design methods.

Based on the practical work, we were able to describe the results in forms of expressions as a methodological frame for the design. The expressions found are definitions built on the design experiments: we see them as explanations aimed to widen the understanding of an individual design process.

By describing the changes in the visual information, we focused in this stage of the project on finding ways of describing the pattern manifestation and formation on the garments. The expressions found in our experiments describe different forms of pattern translations: they illustrate how certain expressions can be formed using design elements related to both body and space when creating temporal patterns.

The expressions are described in a simple way as outcomes of the design process and, also, illustrate methods to create them. The definitions are intentionally formulated as basic descriptions for the designs; in this context, they aim to illustrate fundamental concepts of pattern formations. Through pattern descriptions, the definitions communicate our understanding of the basic expressions that appear as visual changes in the garments, i.e. in terms of shape and repetitions: they influence the way in which wall interaction and movement should be related in the next design.

As a way to contextualize our exploration of temporal patterns as a mediator between body and space, the context for the exploration has been set to a performance where a dancer translates the “informative state” of a wall as traces on the clothes. Thus, the wearer of the clothes is able to pattern the body in communicative ways through near-field interactions in space. In this way, the performance illustrates an example of how space could reveal temporal information which may only be discovered through direct interaction. Alternative programming design of the walls would open up other possibilities, where information could be programmed in various ways as heat patterns in the dynamic elements of the walls, discovered only through close interaction as patterns on the body.

These temporal expressions could be used as information or communication in playful spatial interactions forming the context of a performance or opening new ways to communicate, where the setting is defined by the relationship between garments, body and space. Directing ways of moving in space through clothes and walls, the expressiveness of the movement can be enriched by the expressiveness of the dynamic patterns occurring on the clothing.

In Reptition, the dancer was asked to connect the elements of the setting, i.e. the walls and the garments, in repetitive movements and the performance focused around the idea of repetition. However, the dancer was given no instructions regarding different possibilities the garments had to visually express the repetition through movement. Thus, the intention of the next design will be to give the dancer information on the way basic pattern expressions are formed, i.e. having the methodological framework become a platform for discussions. We aim to further explore how the design of the movement can be added in the initial setup of the performance to influence the textile and fashion process and, in doing so, we aim to enrich the pattern descriptions found in the present project.
References


