# Understanding the complexity of designing dynamic textile patterns

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## ABSTRACT
Through a smart textile design project we have identified two sets of complex issues generally relevant for design with state changing materials. Specifically, we show how the temporal dimension of smart textiles increase the complexity of traditional textile design variables such as form and colour. We also show how the composite nature of smart textiles creates a series of interdependencies that make the design of the textile expressions additionally complex. We discuss how these forms of complexity provide opportunities as well as challenges for the textile expressions, and we show how we dealt with them in practice.

### Keywords
Smart textiles, textile print, thermo chromic print, dynamic patterns, material composites, complexity, design practice, design tools

## INTRODUCTION
Smart textiles, and specifically the combination of electronics and textiles, can be seen as textiles that in one way or another are able to change recursively between two or more states of expressions. They thereby provide a stronger temporal dimension to the design variables (i.e., colour, form, texture) traditionally found in textile design [7]. For that reason, the design, and the process will differ. New developments always pose new challenges, but the challenges in designing with smart textiles are not just a matter of obtaining sufficient skills in the disciplines involved (e.g. weaving, printing, electronics, programming). We have through a practical design project identified two sets of complex issues specific for designing with smart textiles. One pertains to the composite nature of smart textiles and the other to their temporal dimension.

This paper looks at how the temporal dimension and interdependencies within the composite and among the design variables affects the design of smart textiles. Through a specific experiment with a woven textile printed with thermo chromic ink with state changes controlled by a computer we discuss how these forms of complexity provide challenges as well as opportunities for the textile expressions. In some cases, we also propose strategies, and tools, which we developed as means to manage the various cases of complexity.

The temporal dimension is a central and unavoidable design variable in, for instance, interaction design where the computer is the primary material or medium. That said it is not always dealt with as conscious variable in the design choices. In the "Slow Technology" project Hallnäs & Redström [2] pointed out how the computer's transition from a solitary tabletop object into being embedded in every object and environment demanded an increased understanding of how the ongoing changes of expressions affects our environments. In another project, Bergström *et al.* [1] discuss how computational materials comes to be in context over time because of how their expressions changes over time quite often as a consequence of specifically contextual changes. They propose to make low-fi large-scale prototypes as a practical method to achieve an understanding of how a particular material will come into being in context over time.

In traditional textile design as well as in material science it is well established that there are interdependencies in the design of a textile or a composite material [3, 7]. Indeed, to some extend textile design can be understood parallel to the design composite materials. Every combination of materials, every design choice, enhances or enables something, and suppresses others. In textile design, for instance, the focus can be on the expression and quality of the textile whereas in developing composite materials the focus can be on developing new (combinations of) material properties. When we design smart textiles both cases of interdependencies are at play.

The following section contains a description of the practical project Recurring Patterns that forms the basis for our analyses. The two main sections contain complexity analyses, and methodological suggestions rooted in the temporal dimension and the material interdependencies respectively. The final section contains a discussion of the advantages and challenges of that these complexities entail.

## RECURRING PATTERNS: PROJECT DESCRIPTION
In our current research program, we explore how and what we can design with smart textiles [4]. In this project, we had the opportunity to work with a furniture company and thus investigate some of the practical aspects of designing with smart textiles.

The outset for the design was a weft ribbed cotton fabric, with conductive steel threads attached on the backside at every five millimetres in the weft directions using the stitching tie technique (see Figure 1).

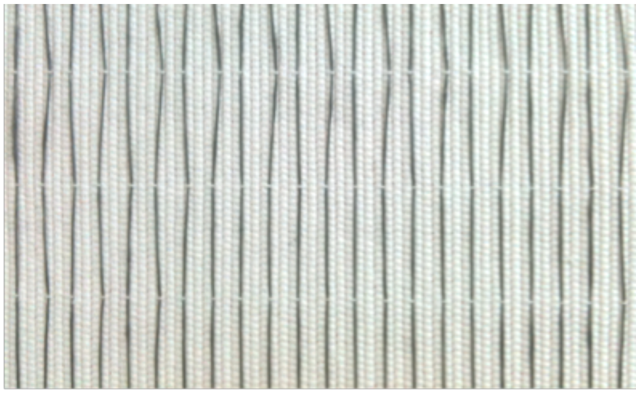

Figure 1 Weft ribbed cotton fabric with conductive threads

This fabric is intended as a canvas for print with thermo chromic ink. When running current through the conductive threads they heat up and thereby cause a colour change in the print along each thread. Thus, the design task was to develop the canvas, the prints as well as the conditions for the changes, possibly with an interactive dimension.

Ire Möbel provided two footstools as well as the expertise and manpower to upholster them with the textile we produced. We designed a different print for each footstool, as a way to explore more techniques and expressions. Both prints are made from combinations of thermo chromatic ink and pigment colour. One print is made from a magnified picture of a knitted textile, where one part of the knitted structure disappears in the heated state of the print (figure 2). The other is a collection of geometric patterns printed in a colour palette consisting of several dark grey nuances, which change into a variety of colours when heated. Some of the patterns in this print exhibit form changes when heated, and others change only colour (`Figure 3`).

A series of Arduino boards placed inside the footstools controls the current running through the conductive threads which caused them to heat and in turn change the colour of the thermo chromic ink. Two textile pressure sensors [5] placed one in each end enables some degree of interactivity. The setup can be configured to suit specific contexts. For the exhibitions at Stockholm Furniture Fair and at Salon del Mobile in Milan, for instance, the colour change in the footstools needed to be as noticeable as possible to attract attention. Thus, we made the textile on the one stool change colour in a looped pattern and on the other only when someone activated the pressure sensors, i.e. by sitting on it. Other situations and contexts of use may have other demands on the temporal expression and interaction.

Figure 2 Footstool with a textile structure pattern.

Figure 3 Footstool with a geometric pattern

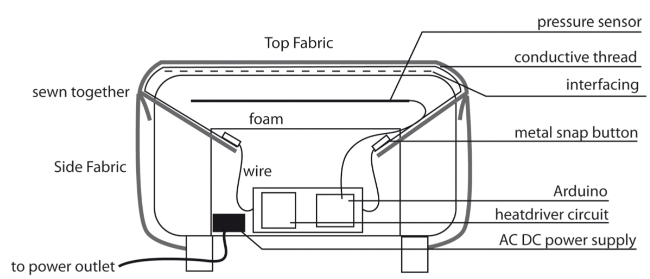


Figure 4 Illustration of the components used in the prototypes.

**DYNAMIC DESIGN VARIABLES**

As argued in the introduction the recurrent change of expression in this sort of smart textiles poses a new complexity to the design task. In the Recurring Patterns project, for instance, this complexity is partly seen as a consequence of the gradual transitions between the cold and the warm state of the printed expression. The conductive threads that are used to control the colour change, take time to heat up and to cool down. This gradual temperature change creates an equally gradual colour change and thereby adds shades and even other colours to the expression. Obviously, this enables a whole new range of complex expressions but it also creates a new set of considerations to the design process. Below is an analysis of what this complexity means to the traditional textile print design variables of colour, form, and rhythm.

**Colour and colour palette**

For the Recurring Patterns project we used two types of colours: the thermo chromic inks, which change from opaque to transparent at 27°C, and pigment colours, which are constant and unaffected by temperature change. By mixing the two types of colours, it is possible to create a range of colour changes where part of the colour disappears, and other parts remain (i.e. going from dark grey to light blue or changing colour tone from green to yellow). Dynamic patterns based on these types of colours can therefore change between two different expressions Worbin has described this as an alternation between two states: "a reversible pattern changes from one expression into another or several others, and always changes back to its initial expression. The pattern can also be described as A B A" [7, p. 49]. When looking at the pattern and specifically the colour mixing in Recurring Patterns project it becomes apparent that this description should be expanded to also encompass the transitions between the states of A & B. Thus, the change of colour would probably better be described as: A → B → A.

A dynamic colour can be seen as a colour scale of nuances in-between its colour at an ambient temperature to its colour at a heated temperature. Diagrammatic this could be described as A → B.


Figure 5 Colour scale that gradually changes from colour A to colour B.

The transition from A→ B is not just a matter of grading. The nuances in-between the end colours can be influenced by how the thermo chromic inks are combined. By mixing several thermo chromic colours with slightly different transition temperatures, it is possible to add completely other colours to the colour scale. This possibility was used in the geometric shaped version of the Recurring Patterns design. In one example the colour changes from grey to transparent, passing through several shades of magenta. An expression achieved by adding a small amount of thermo chromic magenta to the thermo chromic grey colour.

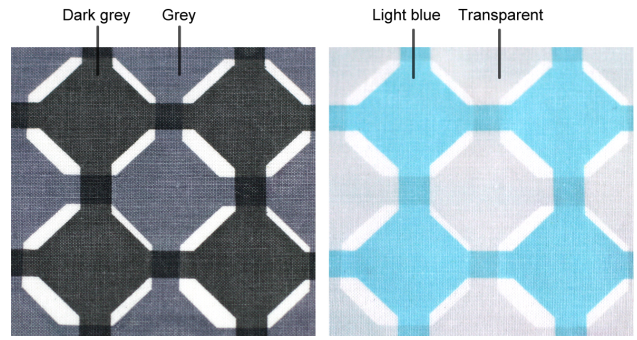


Figure 6 Left: Print sample in ambient temperature. Right: The same print sample in a heated state. Part of the pattern has changed from grey to blue, and the other part from dark grey through magenta to transparent.

The gradual change and combinatorial possibilities with this type of print create a complexity in how colours are combined in a design. Depending on how the heat element is programmed, each part of the print can be in its original state, in a heated state, or gradually changing in-between. This means that each colour added to the colour palette brings a whole range of nuances that can be combined in all possible stages with the other colour scales in the palette. At any point in time, is any combination of these nuances is possible. Figure 7 describes the complexity in a colour palette with three dynamic colours, showing two possible combinations of nuances at two different points in time:

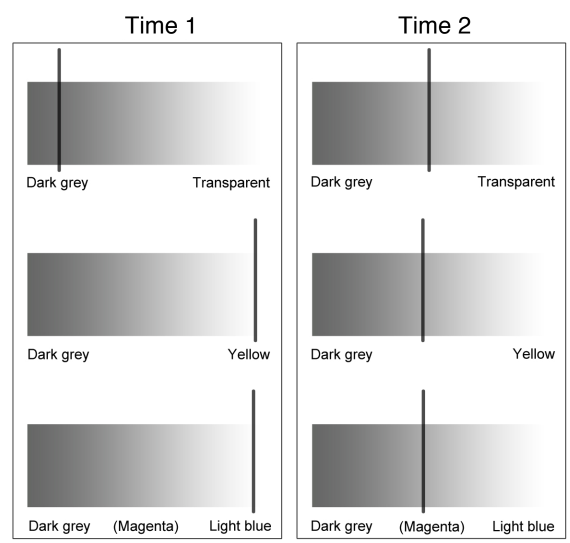


Figure 7 This scema describes the complexity of a three colour palette by showing two possible combinations of nuances at two points in time

In the prototypes constructed for the Recurring Patterns project reaching the transition temperature only took ten to twenty seconds, while the cooling down would take several minutes. Thereby causing the longest period of time the surface was changing to be when it was cooling down. The nuances that are in-between the fully heated and cooled colours therefore provide a significant visual aspect of the overall expression.

With this complex colour variation, designing the colour palette becomes rather challenging. Essentially because as soon as more than a few colours are at play it becomes difficult to grasp how each possible combination will work together. In the process of designing the Recurring Patterns sketching the colour palette by hand or on computer was therefore, almost completely, replaced by mixing colours and testing prints in the printing lab. By placing different combinations of samples together and study how they changed under the heat from a blow dryer we were able to make the selection of colours.


Figure 8 Left: Colour palette sketch, with TC colours in various stages between heated and cooled. Right: Notes describing colour-mixing tests.

**Form and pattern**

When working with dynamic patterns it is not only colour that can be temporal, form is also a dynamic design variable: "a dynamic form could implicitly contain all sorts of conventional forms as it varies from time to time, at one moment it displays one geometric structure, later it changes into another, and so on." [7, p. 266]

How each form element will behave when heated, affects the expression of the design and specifically its relationship to the surrounding forms in a composition. By combining forms that disappear, change colour, or stay the same, it becomes possible to design a pattern where the relationship between elements in the composition changes at different temperatures. The considerations needed when designing a static pattern are still relevant when designing dynamic forms and patterns, but they are multiplied. It is no longer just about building up one composition of forms but about building up compositions of compositions of forms.

Figures 9-11 are prints made in the Recurring Patterns project, which illustrate how the relationship between the shapes in the design can change when the surface is heated. Figure 9 and 10 show how the same combination of forms changes in different ways depending on how the thermo chromic ink and pigment colours are placed in the composition of the pattern.

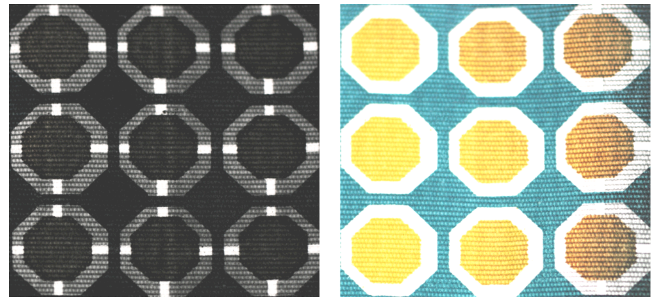

Figure 9 The first version of the same combination of forms. Left: shows the pattern in ambient temperature. Right: shows the pattern has been heated.

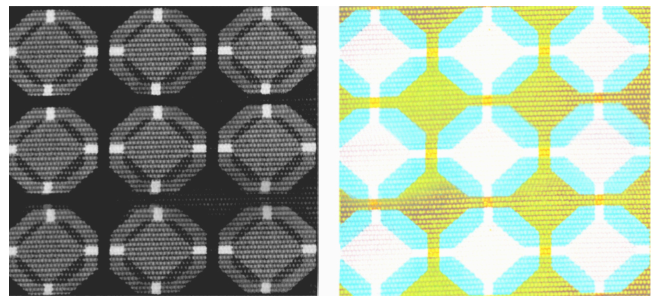

Figure 10 This is the second version of the composition in an ambient and heated state. (The forms are the same in both prints but print colours are different, the two versions are therefore slightly dissimilar in ambient temperature.)

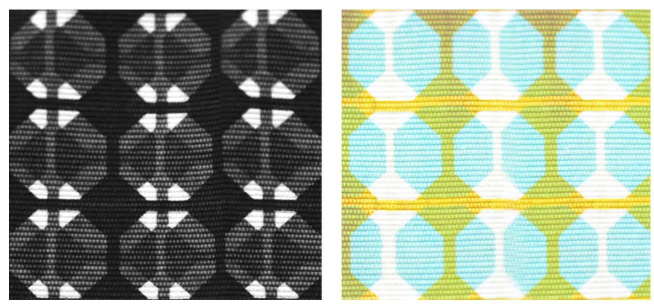

Figure 11 Left: Print sample in ambient temperature. Right: Heated print sample.

When one area changes that will have an influence the expression of the rest of the surface. Working with a textile that can be programmed to heat up sections independently means that at any given time is it possible for each part of the surface to be in its ambient state, in its heated state, or somewhere in-between. This type of complexity makes it possible to play with the relationship between shapes, both in the small area where the heat change takes place but also in relation to the printed surface as a whole. Examples of how this possibility can be used to transform the overall impression of a pattern can also be seen in Worbin's project "Textile displays" [7] where the prints go from repeated to placement print by changing how the heating elements behind the textile are programmed.

To design a composition of compositions can obviously be difficult to do without the right tools. The design of the geometrical pattern for one of the footstools (See Figure 12), was the done by extensive sketching with simple CAD programs but primarily by sketching directly in the printing lab. Nonetheless, the complete expression was not really understood until the printed fabric was put together with a heating sequence in the final prototype. The lack of overview and the numerous combinations of changes meant that it was close to impossible to actively design every expression with the tools at hand.

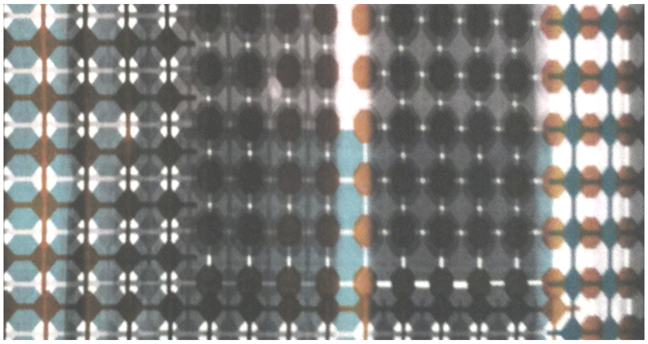

Figure 12 Geometric pattern, showing several types of form-changes occurring on the same print.

One way to reduce the complexity of the dynamic pattern is, of course, to reduce the number of combinations. By using only a few shapes and work with the same change in all areas of the surface the design tasks need not be any harder than traditional pattern design. We used this strategy in the design of the "textile structure" pattern, where the colour scales and shapes where combined in the same way all over the surface.

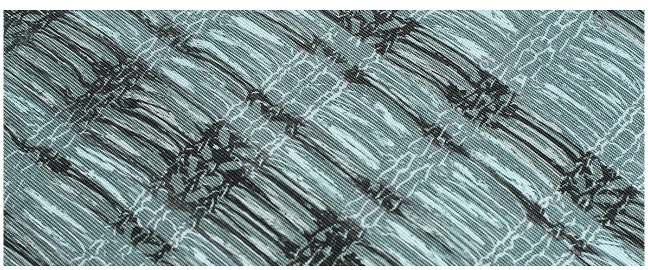

Figure 13 Textile structure print with one type of form change.

### *Sketching tool*

When developing ideas for the patterns, we needed a way to quickly evaluate their transitional expression in the exact way they would happen in the final prototypes. We therefore developed a physical sketching tool from a piece of the cotton fabric with the conductive threads, a driver able to control up to ten threads, an Arduino board, and a max/msp graphical interface. This combination made it relatively easy to program the heating sequences on the Arduino board. This tool enabled us to print sketches on fabric and immediately se how they would work with different types of heating sequences. The size of the tool meant that it still was not possible to grasp the whole expression of a pattern, but it made it significantly easier to become familiar with the dynamic expression in the sketches.

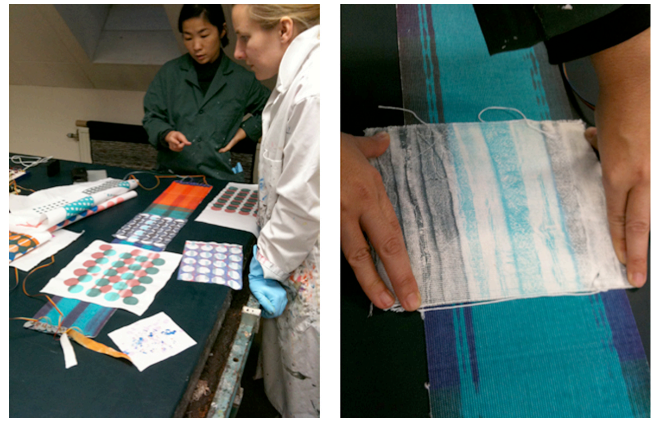

Figure 14 Left: The Sketching tool is used to evaluate printed pattern sketches directly in the printing lab. Right: Printed samples would be placed on the heat element, to see how they would change when heated.

## Time & rhythm

Traditionally, textiles are given their final expression in the making (i.e. during weaving, felting, or knitting), and in after-treatments (i.e. by printing, shrinking, or dying). The expression of a dynamic textile pattern, on the other hand, can be created and re-created through the program controlling the dynamics of the pattern or by making the dynamics dependent on contextual factors that can be sensed [1]. Indeed, the temporal dimension not only influences the design variables colour and form it also calls for the specific design of a temporal form—a rhythm. Even if the temporal form is made dependent on some kind of contextual change, the responding expression is still to be designed. Designing the temporal form becomes complex because it happens over time—we cannot in one moment see what will happen in the next, but more important because the heating and cooling does not happen in an instant the temporal expressions might overlap and thereby create new unpredictable combinations. Moreover, here we have even left out the cases of making the changes contextually dependent which ads a whole new layer of unknowns to the design process.

The heat sequence in a dynamic pattern is built up from a number of individual surface layouts (See figure 15). The composition of each individual layout is determined by the positions, sizes, and intensities of the heated areas. A new surface layout can begin even if the sections are still in different degrees of cooling. The expression as seen at one point in time, is therefore, likely to be a combination of large number of different size and placement designs.

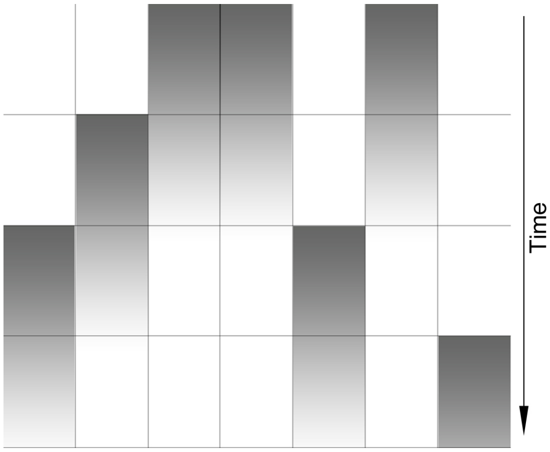


Figure 15 illustration of how the layout of the heating overlap in a composite with 7 individually controlled heat elements.

In the Recurrent Patterns project it was possible to heat the surface in 40 individual stripes. Each stripe could be turned to full heat for a few seconds at the time and each used a couple of minutes to cool down. Again, the combinatory possibilities are staggering, but design is not necessarily mathematics and a significant number of combinations might be ruled out simply because they do not look good. Thus, before we started to sketch the temporal patterns we needed to see what the changes actually looked like. For example, we studied different intensities of changes occurring all over the surface at once as well as changes growing from one end to the other.

After gaining some familiarity with the possible expressions of the temporal patterns we needed a way to sketch and discuss the layout of the temporal pattern. For this, we developed and used combination of a "music sheet" and a graphical interface to the programming of the pattern.

*Sketch tools for the heating sequence*

The sketch tool for the heating sequence became a combination of a "music sheet" where it was possible to mark the heating of specific sections and still keep track the previous and the following layouts. It was, however, not really possible to depict the intensities and thus the overlaps of expressions. So in a sense it is comparable to sheets of music; it still takes a skilled player to interpret the notes successfully. The graphical interface made it easy to transfer the sequences from the sheets to the Arduino controlling the heat and thereby to rapidly test or merely adjust the temporal forms.

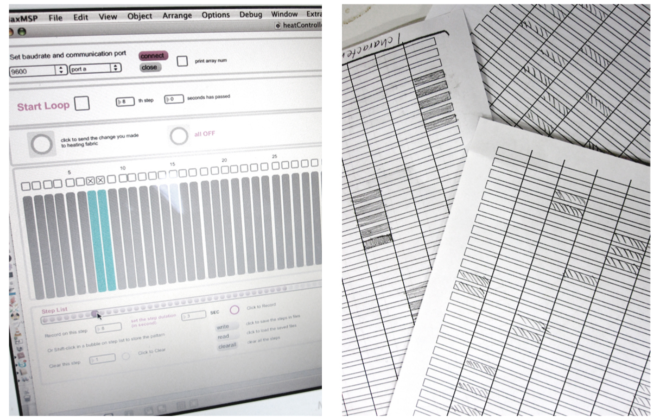


Figure 16 Left: the graphical interface to the computer programme. Right: the sheets used in the heating sequence design process.

## INTERDEPENDENCY

Interdependencies are the other aspect that gives rise to practical as well as conceptual complexity when working with smart textiles. In the Recurring Pattern project we identified what makes sense to talk about as two areas of interdependencies even if they, to some extent, also influence each other. One is found in the composite form of the material, and the other in the combination of the dynamic design variables and their corresponding complexities. The following text describes the two areas of interdependencies further by giving examples from the project.

### Designing the composite

In any composite material, the material properties are not just the sum of its component's properties. Instead, they represent the result of a delicate negotiation between restricting some properties and enabling others [3]. Indeed, in this negotiation often enabling or enhancing one material property will directly restrict another. If the outset is seen as a tree of possibilities each choice will cut off a branch and its sub-branches. Hence, the consequences of a choice can sometimes be difficult to judge in advance. A smart textile is inevitably a composite material and thus also inherits this interdependency in its design.

In this case, the main components of the composite are a woven cotton textile embedded with steel yearn, a pattern printed with thermo chromic inks and pigment colour, a microcontroller on an Arduino board, an array of mosFETs as the driver circuits, and a computer program. One example of the interdependencies that we encountered while developing this composite is the relation between the conductive thread, the cotton yarn, and the sensitivity of the thermo chromic ink (which reacts at 27 °C). The conductive thread attached to the woven cotton using the stitching tie technique should be able to produce enough heat in the fabric to reach the transition point of the thermo chromic ink. Furthermore, the material, which constitutes the primary part of the fabric, should be susceptible to the thermo chromic ink as well as be resistive to the concentrated heat produced in the threads. The material should also be dense enough to insulate the conductive threads yet permeable enough to let the heat through. Moreover, the quality of the material still has a strong influence on the durability and expression of the finished textile and thereby for which purpose it is suited.

Another example is the combination of a computer and a textile. Separately they can be used in innumerable ways. In unison they restrict each other's potential, but simultaneously enable completely new expressions. More specifically, the textile must be able to express at least two states to accommodate the temporality of the computations and the computer program must be restricted (programmed) to effectively express something specific in the textile. In Recurring Patterns the computer is programmed to control the switches on the array of mosFETs, which in turn control the flow of current through the specific lines of conductive threads.

The strategy used in the Recurring Pattern project was to develop the composite starting with one material element and then gradually adding others. This strategy made it possible to understand the consequences of each new addition, and therefore to relate the new potential to the choices already made. In this case, the woven fabric with the conductive threads served as the starting point. The linear layout of the heat elements, for instance, became a strong signifier for the later design of the print layout. The downside of this strategy is that the resulting material composite could perhaps have accommodated the desired purpose better if some of the choices made in the beginning were kept open till the end.

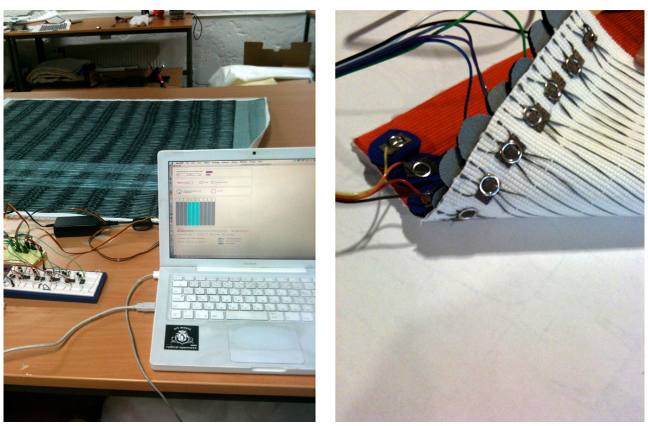

Figure 17 Images from the composite design process.

**Designing the textile print**

The design of the textile composite combined with the complexity within each of the dynamic design variables also increases the complexity when composing the overall expression. Here demonstrated through two examples.

Traditionally, the design of form and colour consists of a series of interdependent choices at least when the form is expressed through the colours, for instance, some colours appear to be in the foreground when combined with their contrast colour. When designing with dynamic colours, and through those dynamic forms, makes it is possible not only to change the forms and colours, but also to change the relation between the forms. For example, where one form may appear in the foreground before the colour-change it may have shifted to the background after the change. More generally, the colour palette will simply regulate the forms and their transformations and vice versa.

Another example is about how the layout of the heating elements will have a significant impact on the way each form can change. In the textile composite for Recurring Patterns, the heat elements can warm up sections of 20mm wide stripes over the width of the fabric. Obviously, this places some constraints on how the forms can change. We could either use it as an element in the pattern or find ways to hide it through the composition of the forms. Another challenge was in the distribution of a pattern over more than one heat element. When, for instance, a form was placed over two different heat elements it could also be transformed by both. This meant that the same form could either be completely changed, half changed, or remain unchanged depending on the temporal pattern. Thus, the form compositions are also dependent on the temporal forms and vice versa.

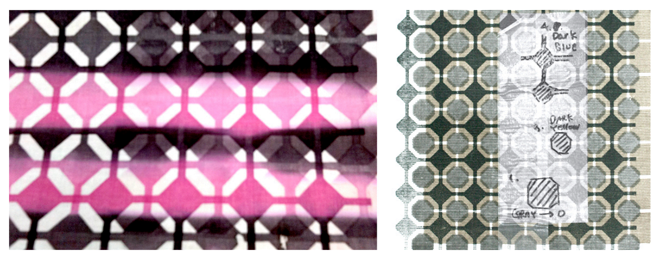

Figure 18 Left: A printed sample placed on the sketching tool with two heat elements activated, the line shape of the heat element has a strong effect on the expression of the change. Right: A printed sketch of how form and colour could be combined. The notes on the sketch describe how the different forms react to heat.

When designing textiles, sketches are often done on paper, with CAD programs or directly on fabric. In this case, such techniques only took us so far, partly due how the interdependencies among the design variables was difficult sketch. When designing the dynamic print, doing test directly on the materials and evaluating them on the sketching tool became a way to better grasp how the combinations of colour and form worked in relation to the layout of the heating elements. The sketching tool became a way to see how the dynamic variables influenced each other already in the process of designing the pattern.

**Discussion**

Through this project we have identified a series of practical as well as conceptual complexities that arise when designing with such state-changing materials. Moreover, these materials are interdependent compositions of several material elements.

Some of the complexities can be turned into powerful expressions if they are mastered sufficiently. The question is how to master them. We have proposed some ad-hoc strategies and developed some sketching tools whose principles at least could be transferred to other projects.

Yet, there is a special issue which we haven not yet addressed, namely, the fact that most of these smart textiles are made for a specific project and thus to a large extend will always be novel in the design process. In traditional textile design it is possible to become really skilled in certain techniques, but the same is difficult to achieve for these smart textiles, as they are rarely mass-produced. Experimenting with the properties and potential of the smart textile at hand will therefore be a significant and time-consuming part of the design process, especially if the smart textile is also open to be changed in its composition.

Nonetheless, we do believe it is possible for textile designers to achieve some level of familiarity with the dynamics of the classic design variables, when it comes to textile prints. We do believe that identifying some of the complexities can be a start to better understand the design space these materials afford. And we do believe that with some effort and after other iterations it is possible to develop more general sketching tools and strategies to aid the designer through the design process.

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