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**ArcInTexETN**

Marie Skłodowska-Curie actions European Training Network (ETN)





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OF TEXTILES  
UNIVERSITY OF BORÅS

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# INTRODUCTION



## Challenge and context

A fundamental challenge in design research today is to define the design programmes that suggest how we can turn our day's scientific knowledge and technical development into design for new forms of living that will provide foundations for a more sustainable way of life.

As natural science and engineering science introduce new materials and new technology, there is an increasing need to explore their possibilities and consequences for the design of our future living environments.

In this book we discuss and display efforts to meet this challenge by connecting architecture, textile and fashion design, and interaction design in explorations of the expressional possibilities of modern technology for dressing, furnishing and building for adaptive and responsive forms of future living.

This is done with focus on textile thinking as a programmatic and methodological foundation that could open up for a new generation of interdisciplinary trained and high-level educated architects, textile and fashion designers, and interaction designers, who build their work practice on new ideas of material thinking and design thinking with an emphasis on sensitive design expressions for reflective living.

Applying technical innovations in order to improve our ways of living is a matter of design. Explorations of possibilities and consequences with respect to the application of new technology require experimental design research. As this is not an area of research initially open for empirical studies, however, we will first need to explore possibilities and reflect on consequences by designing. Applications of technology address the ways in which we design, both from a far-field perspective (architecture) and a near-field perspective (textile and wearables/fashion design), but also very much the ways in which we relate these perspectives; the interfaces we build and the communication systems and devices we construct (interaction design).

Ways of living are intrinsic to both architecture and textiles as areas of design; from near-field clothing design, fashion design, and furnishing to far-field interior design and architectural design, from dressing us and our bodies to situating us in a living space: how to relate the near-field and far-field perspectives of design expression is a central issue as we try to use technological innovations to improve our ways of living.

Design for sustainability is a vast subject covering a wide range of variables from almost all areas of design: materials, construction and production processes, use, waste, etc. Consequently, the range of different research perspectives on the issue of sustainable design is also very wide.

A central working axiom in this area of research is that design for future forms of sustainable living entails fundamental changes in ways of living and also requires radical changes in design thinking. The primary challenge for practice-based design research is to experimentally explore the nature of these changes. Such research includes everything from materials experimentation to forming scenarios in a sort of archaeology of the future.

Here we would like to formulate the working axiom in a slightly more precise manner by saying that these changes go in the direction of more reflective ways of living.

Turning scientific knowledge and technical development into design for new forms of living may focus on the functional solutions of given problems, but could also focus on expressional possibilities that open up for ways of living a reflective everyday life. It is this focus on expressional possibilities that is the main theme in this book. This programmatic direction of research contributes to the “material turn” in design research by introducing an “expressional turn” in an area which has a strong focus on technical solutions and different forms of evidence-based design.

This book is about visions, ideas, reflections and results taking on this fundamental challenge of design and design research with a point of departure in the programmatic idea that deepening the connections between textile and fashion design, architectural design, and interaction design will open up for the establishment of a new, reflective foundation on which to base the design for living in an age of technological innovations.

These visions, ideas, reflections and results discussed in the book are all, in one way or another, related to work carried out within the Marie Skłodowska-Curie ArcInTex European Training Network (ArcInTexETN), a European Union funded project 642328 with partners

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## Ways of living and textile thinking

What, then, is design for new ways of living?

A starting point could be that we are looking for a different expression of living, a different expression of the things, locales, and interactions that surround us and constitute us.

Must it be like this? Metal, plastics, concrete, wood, stone, solid composites... They are all precise, definite in some sense. It is a closed world with given placeholders, and very much defines our ways of living; the ways we dwell, the ways we communicate, the ways we travel, the ways we work...

Yes, it is precise, it is safe, it is solid, it presents itself as the obvious choice by its very nature, but also by the traditions we built around it. It is the fundamental, discrete nature of our technology. It is closed, not open, it is rigid and silent, not adaptive and responsive.

There is of course another side, full of a more mystical, continuous complexity.

We do not walk and run that way, we do not eat and drink that way, we do not sing and talk that way, we do not dress and dance that way... There is a fundamental

## INTRODUCTION

duality here that forms the foundation of our current ways of living. The interfaces that build bridges in between these two worlds are central components of the ways that living expresses itself.

Ways of living as the overall form of the things that we do relate to the general character of the fundamental worlds of living, bridging them, what we do and where, the actions and locales of living, the places where all of these actions take place.

No matter what forms these worlds take, it concerns relations between what we ourselves do and what things do. Living means doing something, and doing something involves me doing something and some things doing something somewhere.

When we do something it takes place somewhere; there is a specific locale where this takes place, from the more concrete places such as this particular house to the fundamental locales that open up the abstract places to certain kinds of actions.

Ways of living can be seen as the ways in which we build and inhabit the fundamental locales of living and relate them to one another. This is also a lens through which we can view and develop design for new forms of living.

There are actions that reside in a duality between what we do and what things do. This is what an interaction is; an action as it is defined by this duality, between me doing things and things doing things – a thing is then just that something other than me and also something done. These actions take place in fundamental locales of living, the concrete and abstract places we seek out and place ourselves in as we do certain things.

A way of living is by abstraction a definition of living. It defines the fundamental dualities of living; on the one hand the ‘where’ of living and on the other hand the ‘what’ of living.

What, then, is design for new ways of more sustainable ways of living?

In general, ‘sustainability’ is the ability to continue a defined behaviour indefinitely. This can then apply to environmental sustainability, economic sustainability, social sustainability, and so on.

A secular, mundane interpretation of this is that we should take care, try to do things in a smarter way, and not be wasteful, not overspend, and avoid draining resources without considering what will happen next. We should not take the idea of sustainability in a literal sense, as it is just a way to express an ideal horizon.

Taking “the ability to continue a defined behaviour indefinitely” seriously is something quite different.

Taking this idea seriously calls for the stability of fundamental locales of living and a certain permanence of interactions. The places for actions must be there and be open for certain actions. There is clearly a certain generality involved here, as due to wear and tear it is clear that we cannot all expect to be able to drive this, my specific car, indefinitely or wear these, my specific jeans, indefinitely. Moreover, the ability to continue a defined behaviour indefinitely is not something that can depend on me. So, what are stability and permanence all about? This is what makes certain actions as such always possible; drinking water, dancing, travelling, eating rice. To travel is both a timing and a spacing action; it takes time and it takes place. To say that travelling is a sustainable action is to say that the definition of what that is does not depend on specific actions bound in time and space for example.

Behaviours are manners/ways of doing something; the ways we walk, the ways we talk, the ways we sleep, the ways we eat. They reside, so to speak, in (the logic of) the definitions of doing something in a specific way. To say that a certain behaviour is sustainable is to say that the fundamental actions that define the behaviour are unbound with respect to timing and spacing.

Taking this literally is, of course, a kind of higher order nonsense. Our existential angst has its very foundation in the insight that things are finite both with respect to timing and spacing in a certain, non-trivial sense.

There are at least two different ways out of this. The primary, rational path we can choose is to take the idea of sustainability more figuratively, and look for ways to live and work while being more careful and smart with respect to resources and our environmental footprint.

Another path we might take is to embrace the idea of sustainability in a more literal sense, as something to believe in.



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There is a central difference here between:

(A) Sustainability as a programme for solving well-defined problems with respect to the functions of our environment, and

(B) Sustainability as a belief system with respect to a careful and thoughtful way of living.

As a guiding programme for design, (A) concerns the introduction and expression of functional solutions to given, well-defined environmental problems, while (B), on the other hand, concerned with introducing and expressing new forms of living on the basis of a 'theology' of sustainability, a dogma, a systematic explanation of the fundamental principles of belief that guide certain ways of living.

Sustainability is not just about solving problems, it is also about belief; belief in certain ways of living.

Our planet will change no matter what we do; the sun will say goodbye some time in the future, making the prospect of our earth as a locale but a dream. A sustainable way of living is in this sense just a dream, the destiny of life as we know it. However, we can still believe that certain ways of going about things make more sense than others. This does not, of course, mean that it must be something in lack of a rational foundation, like believing in trolls.

In the first case, functionality is the main issue: how to handle resources in a smart way, how to build effective transportation systems that leave as light footprints as possible, and so on. In the second case, expressions of living are equally important. Organic farming as an expression of sustainability is one such example. Genetic engineering in farming might here be seen as an expression of the carelessness of modern technology.

When designing for new forms of living it is not only a matter of neutral expression of functionality, but also very much a matter of expressing a change in living. A systematic theology of sustainability can here be turned into an experimental design programme that in a more concrete manner discusses sustainability as a way of living. In an archaeology of the future we rediscover the meaning of sustainability as something to believe in. This is by no means to forget functionality, as function lives

by the expressions that we give to things.

One way to outline a theology of sustainability is to state the principles of how we should inhabit the fundamental locales of living so as to keep them open, to make sure that there are still places open for doing the basic things that define living. This will of course be a circle; being open for this something that is what keeps them open, the life cycle of living. Locales are inhabited by interactions, interactions build locales.

Actual interactions depend on specific locales, i.e. concrete interactions always take place somewhere utilising the given locale. Interactions also change given locales. To cut down a tree there must be a tree there somewhere, and once the tree is cut down the place has changed in a very specific way. A sustainable way of living is then a way of living that is based on a duality between interactions and locales, where locales in some fundamental sense still remain here and the same, and not there and having gone through interactions. In cutting down a tree we could have been looking for a place where trees can grow, instead of just looking for a place where there currently are trees that we might cut down. Cutting down a tree, leaving the place alone, it will still remain a place where trees can grow.

Interactions are 'sustainable' if the locales that they depend on remain here eventually open for these same interactions, the good circle. These interactions reside in the dualities between what we do and what things do. They take place in fundamental locales of living, the abstract or concrete places we seek out and place ourselves in as we do certain things. Water resources, for instance, relate to drinking water as water interactions, and water is a spacing locale, where these interactions somehow must build the locale just as the locale opens up for the interactions. Where the circle is broken we can see traces of forgetfulness or carelessness.

Textile thinking is the main leitmotif and programmatic foundation of the work presented here, a conceptual lens through which we imagine, express, connect with, and revisit the locales and interactions that may build future ways of living. Textile thinking here introduces the idea of a near-field perspective when designing the locale, which translates to an extended respect for detail and further influences a larger view wherein the locale determines the series of interactions around.

Textile thinking maps out a 'theology' of sustainability through its way of introducing

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flexibility into the world; there are always ways to come back, to revisit, to rearrange, to restage textile locales and interactions. It gives a specific meaning to the idea of locales still being here:

- Textiles as locale, always here and waiting to become a thing, never there and ready and done.
- Textile as locale, dissolving the borders between locales as houses and locales as clothes, between the scales of the building, the interior, and the body.
- Textile interactions; what connects, inhabits, and builds locales as textiles.

Textile thinking maps out textile architecture and textile interaction design as specific programmes for sustainable thinking in architecture and design. Sustainability is then not an idea of possible infinite repetitions, but an idea of design as an invitation; an invitation to care, to be careful. It is the belief in becoming things, relating interactions and locales in a very profound manner, that defines the design foundations of this invitation.

# THE SCALE OF THE BUILDING

## Introduction to textile thinking for adaptive and responsive architecture

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The practice of constructing human habitats with the help of textile techniques and their encompassing structural logic can be traced back to early settlements. In these constructions, textiles operated either as (a) the dominant protective and form-giving material from which shelters and smaller buildings were assembled, or (b) the instructive – and almost pedagogical – device whose material characteristics – interlock-ability, adaptivity, and flexibility – and derived fabrication methods were transferrable to other suited constructive resources on differing scales. The earliest applications of textile techniques had their origins in the knowledgeable weaving of willow branches, pine straw, hide, grasses, and animal hair into e.g. baskets, fish traps, and other artefacts, some of which are over 10,000 years old (Brigham & Stokes, 1906).

A look at those vernacular structures, like the most primitive huts in Chichibu, Japan or in Terra Amata, France (Pavlos, 2014) – erected almost half a million years ago by *Homo erectus* – suggest an interlacing of natural fibres that constituted a structural envelope with a quasi-textile tectonic, a system that was lightweight, reversible, adaptive, mobile, and whose morphological presence emerged from a natural and tacit play between load-bearing forces in equilibrium.

In these habitats one can also trace the beginnings of mankind's autonomy in relation to given environmental conditions, which in consequence expanded the mobility of early settlers. It granted these early civilisations new ways of living that laid the groundwork for an emerging building culture, and helped in the development process of novel socio-cultural patterns that could take advantage of an expanded geographical territory and more challenging climates. Architecture's role hence transcended providing a mere shelter that catered for the most elementary needs of our ancestors, and began to be a negotiating interface through which a developing culture of society would be crafted and became tangible for the generations that followed. The drawings and etchings of primitive huts by Marc-Antoine Laugier (Eisen, 1755) and Filarete (1451; 1464) imagine a future building culture through

the manipulated reconstruction of the past. Textile principles are actively employed in the designs of these politically charged visions of early building culture. Laugier's hut uses a textile principle for the interlacing of the roof elements; those of both Filarete and Laugier interlock the horizontal and vertical load-bearing members in a complex three-dimensional knot. A related concept can also be encountered in the seminal book *Der Stil in den technischen und tektonischen Künsten* from 1878, in which, using the example of a simple Caribbean hut (Semper, 1878, p. 263) and its method of interior decoration, Gottfried Semper conceived his "Bekleidungstheorie" or 'theory of dressing' (Sorensen, 2018). The architect detects a separation between inner, functional, load-bearing structures and a decorative, often textile layer that forms the interface for human perception and interaction, a building element that transcends the purely functional trajectory and is a semantic device, communicating individual and collective cultural information. Semper argues that, with the help of this crafted, textured, and decorated ornamentation of walls, floors, and ceilings, a transgression is accomplished; from an elementary building activity to the beginnings of an early "Baukunst".

From the the early settlement's textile interlacing of natural fibers to the more culturally encoded applications of textiles described in Semper's book, an intensive quality of textiles can be detected that grants new opportunities for the interlacing of complex contexts beyond the physical. This conceptual quality, which views textiles as thinking models (Ramsgard Thomsen, Bech & Sigurdardottir, 2012) and semantic devices, also lends itself well to an expanded conception of a textile-inspired architectural design that reaches beyond the construction of buildings, and which grants inroads for developing a "relation to various epistemological, socio-political and cultural concerns as a system dealing with the physical world" (Anderson, 1982, p. 112).

In the following passage, five core principles of textiles are described that assume responsibility for this adaptive quality and were relevant for the identification of relevant research questions for all five early stage researchers (ESR) involved in the ArcInTexETN Horizon 2020 project. In the individual and collaborative projects of the ESRs these relationships can be traced in various manifestations and scales, appearing as textile-material systems, conceptual devices, or hybrids of both.

The textile principles investigated in the research projects are:

### **Geometry**

The underlying geometry of textile techniques, be they knitting, weaving, or crocheting, follows a robust mathematical order based on topology. This field of mathematics differs from Euclidian geometry as it is founded on the identification of relational, rather than spatial, properties. The scope of an 'an-exact' temporal morphology is dependent on a rigorous, programmed connectivity logic in an interplay between flexible material properties and animated context. This abstract encoding of potential material behaviours allows a transfer of textile techniques to various scales, while employing identical procedural instructions (Palz, 2012, p. 197).

### **Structure**

Textiles form redundant structures through a spatial arrangement of linear elements that operate best in compensating tensile forces. The momentary morphological actualisation of a textile shape is thus formed through a negotiation between external forces and the local distribution of the material properties throughout the textile itself (Otto & Rasch, 1995). This interdependence between the formal presence of textiles and their spatial, technological (Yablonina et al., 2017), and physical environments compellingly positions them in the material culture of their respective times.

### **Material**

Material properties form the basis of a textile's identity and define its character, structural performance, and functionality. These properties are hard-wired to technological progress in material science and fabrication technology, which drive their applications on many scales. Contemporary materials that are used to make textiles and fabrics incorporate a broad repertoire of knowledge that stems from the fields of process engineering, computer science, structural mechanics, chemistry, and many other fields that create highly bespoke artefacts, products, actions, and applications. Research from other fields (Palz, 2012, pp. 64-69) shows that progress in one of the subdomains of a technique can lead to radical and far-reaching chains of product innovations, actions, and applications, or even entirely new composite technology domains.

### Interface

Textiles operate as semantic devices that inform actions and communicate a variety of contexts, qualifying as “signs” (in a Peircean reading) as they signify, represent, and reference content through a distinct formal identity, interactivity, and material scope. The semantic functions of textiles expand beyond non-visual content as they can operate well as scaffolds and interfaces for other sensory information entities, as shown in e.g. the finishing of textiles with fragrance agents. Textiles accordingly compose their distinct expression through an interplay between various semantic information streams that directly relate to their respective times and cultures.

### Action

The final aspect addresses the performative relationship between textiles and their environments. Through an interplay between geometry, structure, and mechanical properties, a textile interface can be created that is permanently open for performative actualisation. This actualisation, which grants static or animated morphological presences and mandates form-giving factors that act upon it, forms a dialectic dialogue. These agents that lock the textile in distinct formal configurations are shaped from their respective contexts. Such a mediated behavior can be seen e.g. in the case of a dancer’s embodied interaction with textiles; thereby a set of highly individualized and inherited locomotive patterns inform interactions with a textile whose concise joint performance operates mostly below the exact cognitive awareness of the dancer yet mediates individual expressivity, cultural traditions and material performance in a procedural and synthesizing manner.

Obviously this short list of characteristics provides only a superficial indication of the plethora of heterogenous contexts that are buried within each segment, and the complex overlaps between them. What it can provide, nevertheless, is a perspective on the entanglement of textiles – their traditions, materials, techniques, and geometries – within a larger cultural and technological context that allows textiles to maintain their role as a contemporary material system. It can also point to the inherent conceptual implications that are connected to textiles and their structures that can release innovative contributions to a broader network of knowledge fields beyond the material itself.

The innovative and relevant contributions of the ESRs’ projects highlight this expanded understanding of the complex material system that is commonly known as textiles.

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TEXTILE STRUCTURES FOR ADAPTIVE  
AND RESPONSIVE ARCHITECTURE  
(TEXTILE ARCHITECTURE)

Augmented Knit Tectonics: CAD/CAM-driven  
Processes of Textiles in Large Scale

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Tectonics has played an important role in modern and contemporary architectural discourse. Through time there have been many different interpretations for what the term exactly means; it is not axiomatic and therefore free for subjectivity and more individual interpretation.

The term is rooted in the Greek tekton, meaning 'carpenter' or 'builder' (Frampton and Cava, 1995). During the fifth century BC, it evolved into a broader meaning to describe acts of skilled handcraft making. This enclosed the particular craft and creation of art at the same time, a duality that is found in both historical accounts and modern perspectives on tectonics.

German theorists of the nineteenth century such as Karl Otfried Müller, Karl Bötticher, and Gottfried Semper built their understanding of tectonics on the relationship between structural and ornamental elements. In the twentieth century, it promoted arguments encompassing the assemblage of constituent parts, engagement with craft particularisation, and the notion of how visible elements eloquently reveal how a building works (Schwarzer, 1996).

Yet, if we look for common points, it is possible to define this seminal concept as the nature of the relationship between architecture and its structural and material properties (Oxman, 2012). Furthermore, we could complete this definition by saying that tectonics often shows a relevant coherence between material and method of manufacturing.

At present, the addition of digital significance has expanded the implications of tectonics. Digital tectonics initially had to overcome the dichotomy of the digital belonging to an immaterial domain of computer algorithms and tectonics being heavily linked to a material world of construction (Leach et al., 2004). As a result of this interaction, the novel digital tectonic domain has facilitated the fast development of integrative design methods where synergies between architects and engineers leverage the overall scope of building solutions (Weigele et al., 2013). Architecture has thereby inno-

vated building modelling techniques to incorporate the current discourse on material practices and fully exploit novel manufacturing and fabrication technologies. Insofar as these computational processes are enabling mediation between form, structure, and material properties, tectonics is again becoming a seminal and operative concept (Oxman, 2012).

This continuous progression of technological, resource, and material practices makes Semper's Stoffwechseltheorie (2004) useful in a research context like this one, as it provides a theoretical framework to describe material transformations made possible by recent advances in material science and digital design tools and fabrication methods. With regard to the results presented here, textile constructive logics – knitting – are taken as a model to inform material organisation, morphological formation processes, and spatial strategies of tectonic architecture.

Knitted fabrics are extremely adaptive structural systems that can be fully programmed with differentiated material properties and heterogeneous compositions. Their ability to transform raw material into three-dimensional forms invites new synergies between knitting craft and emergent digital fabrication technologies (Steed, 2016), thus leading knitting opportunities to unexplored territories. Knitting technology - benefited from advances in computer numerically controlled (CNC) knitting, machine improvements, and the advent of new composite materials - is rapidly being incorporated into the architectural materials palette. In comparison to woven fabrics, knitted ones are extremely stretchable and conformable, making them convenient for e.g. composites preforms, to work embedded in other materials, or as in-place formworks for concrete casting (Popescu et al., 2018).

Previous research has also introduced knitting on an architectural scale incorporated as a solution in multi-performative hybrid structures (Ahlquist and Menges, 2013; Tamke, 2015) or in combination with pneumatic actuators in reinforced, programmed, and knitted structures, as in the Knitflatable project (Baranovskaya et al., 2016). Knitctonics also tackles the question of material distribution – with differentiated properties – using domestic craft tools, such as small circular flat weft knitting devices, conveniently hacked to be computer numerically controlled (Chaturvedi et al., 2011). Although both of these examples explore the possibilities of knitting, they only utilise yarn sizes that existing machines can handle and produce materials on an architectural scale by simply enlarging the fabric. Further, they work within a larger system in conjunction with non-textile elements (e.g. bending rods). Therefore, their

tectonics pertain to a different class than those based purely on textile-formation processes, and can be performed by themselves. In this way, the textile itself becomes tectonic.

Alternatively, the research investigation presented here proposes a different conceptual framework for augmented knit structures at the yarn level. A reference model to organise digital knit loops can be found in domestic hand knitting devices. This craft technique is an accessible alternative to conventional hand and industrial needle knitting as it uses a frame with pegs and a hook tool, instead of needles, to make the loops and handle the fabric. This knitting device can be understood as a process situated between hand knitting and flat weft-knitting industrial machines, computerised or not.

Two alternative experimental pathways are described and shown in the pictures accompanying this text.

The first follows routes that have emerged in recent years that showed the innovative potential of textilising other materials. In connection to Semper's precepts, textile logics are taken as thinking models (Ramsgaard Thomsen et al., 2012) for architectural design, and actioned through additive fabrication and robotic fabrication, with embedded, differentiated material properties to deliver innovative autonomous tectonics (Del Campo, 2013; Palz, 2012).

Robot-aided fabrication is becoming increasingly present in the digital architectural arena. As with any other digital fabrication pathway, this is mainly because of its potential to transform the digital into something concrete and tangible. Among the major benefits are its versatility for directly mediating between digital instructions, form, and material-formation processes (Gramazio et al., 2014), and full end-tool customisation for material manipulation and symbiotic integrations with ancillary hardware. Further, two inherent fundamentals make robot-aided fabrication an optimal choice: First, there is an obvious correlation between human and machine kinematics, meaning that what is learned from human performance might inform, if not mimic, later automatised processes (Ficuciello et al., 2014). Secondly, and as regards augmentation (by which we mean specifically the act of scaling up), there exists a wide variety of industrial robotic options capable of manipulating anything from small payloads of less than a kilogramme to a couple of tonnes.



## THE SCALE OF THE BUILDING

Here, a knitting pattern form on a sequence of consecutive knit and purl stitches was digitally modelled and parametrically controlled, providing contour information for a robotic arm to extrude a chemical cementitious mix. This experiment explored the possibilities of Soliquid as a unique, large-scale 3D printing process in suspension in a gel matrix, enabling freeform printing.

The second pathway is an alternative to conventional knitting. The mechanical properties of knitted fabrics are strongly related to fabric structure, yarn properties, and fabric direction, thereby defining the behaviour and performance of the resulting knitted structure. However, conventional industrial knitting machines cannot knit with the extremely coarse yarns that unexplored applications in technical fields may demand. Today, large-scale knits are only feasible if made by hand. Therefore, more suitable and less yarn-dependent fabrication processes need to be employed if an exploratory augmentation of the knitted structures for novel application is desired.

Textile machinery is generally product-oriented and bound to a limited material palette suitable for each technology; in contrast, equivalent handcrafting techniques open space for alternative purposes and non-conventional materials. This fact makes them ideal, as in this case, for manipulating and prototyping with non-uniform and graded yarns. Here, a new, holistic, and operative approach to fabrication methods for bio-solidified knit tectonics is proposed.

The Semperian concept of *Stoffwechsel* ('material transformation') is present in both experiments. The main difference is that one relates to time and space constraints. For Semper, this material transformation is a metaphorical image of transformation that evolves through long periods of time – in fact, the history of mankind – and symbolic meanings are transposed from one technology to another. In short, transformation provides instructions or models for one material to change and become another. Whereas in the experiments shown here, transformation is indeed mediated by an embedded, active materiality. The underlying textile logics of knitting organised the material, and in the second stage, this performed transformation, sometimes in near-real-time. This is what Spuybroek (2008) would describe – although in a different scalar manoeuvre (Tramontin, 2006) – as an architecture of continuity, where ambiguity is a dual state of being, form, matter, structure, and skin; a continuous line becoming a vault. Semper's materialism is rephrased in a more processual, active form (Spuybroek, 2008): From a liquid condition to a solid state by means of chemical cementation, from soft to hard tectonics, local transformation is activated

through a bio-cementation process. From tension forces to compression.

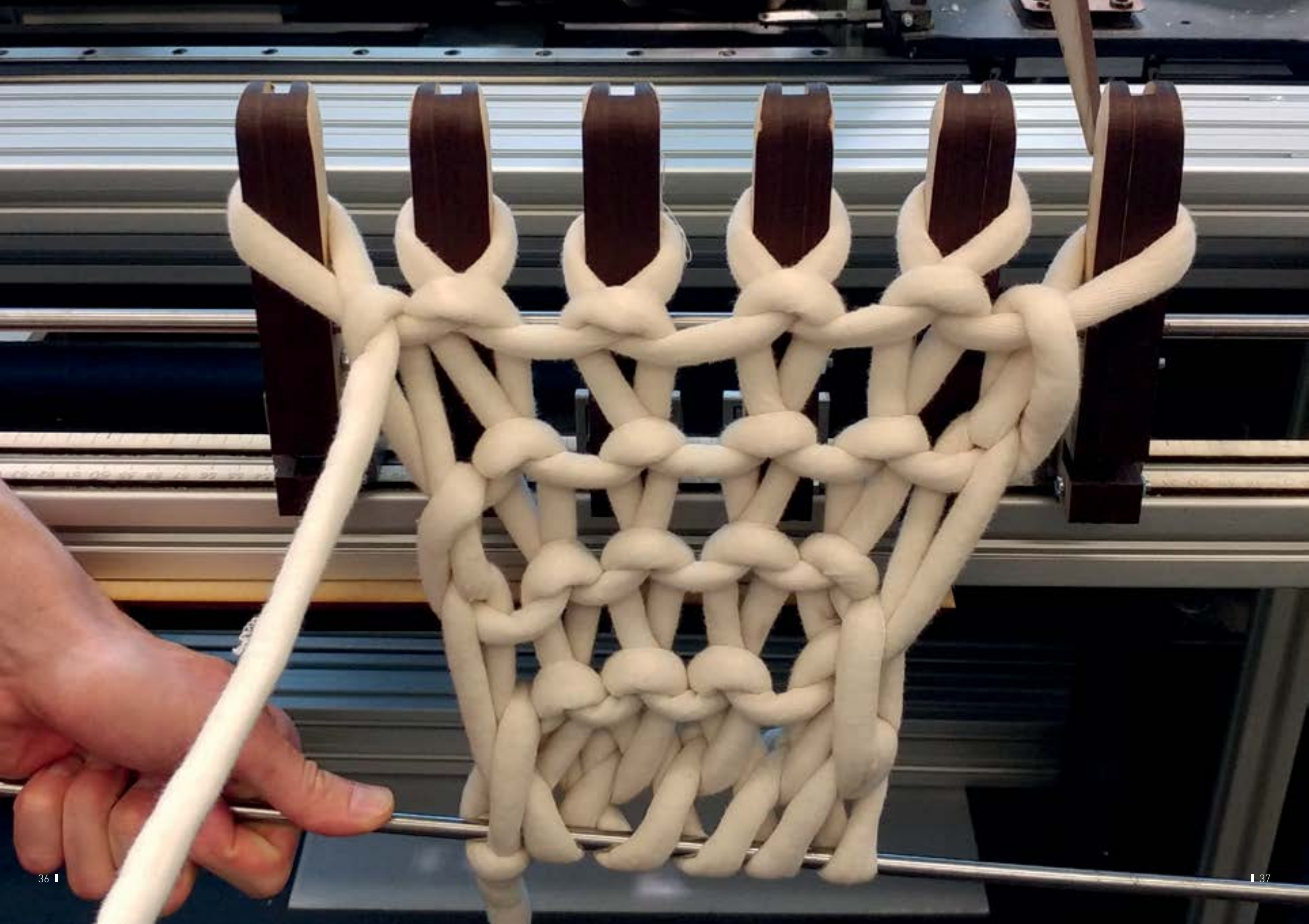
In this context, the augmentation concept emerges not only as an up-scale factor or an increasing process, but also as a means to facilitate an enhanced functionality with amplified material potential mediated by computational tools, in turn promoting non-conventional materiality. Augmented yarn materials are a unique opportunity to design with engineered, new composite solutions with differentiated performance. Yarn here refers not only to long continuous lengths of interlocked fibres, but rather in a figurative manner to the notion of a continuous material to be afterward processed, in this case knitted. This expands the concept of yarn beyond conventional meanings of single- or multi-thread yarn to more complex solutions, such as the cases presented here, to a continuous line of extruded material or to tubular yarns knitted around a core. This kind of yarn composite benefits from a multilayer structure that allows a variety of different material performances to be implemented in the final product. Furthermore, they expand knitting to new fabrication methods, broadening the range of architectural and industrial potentials that these processes may facilitate.

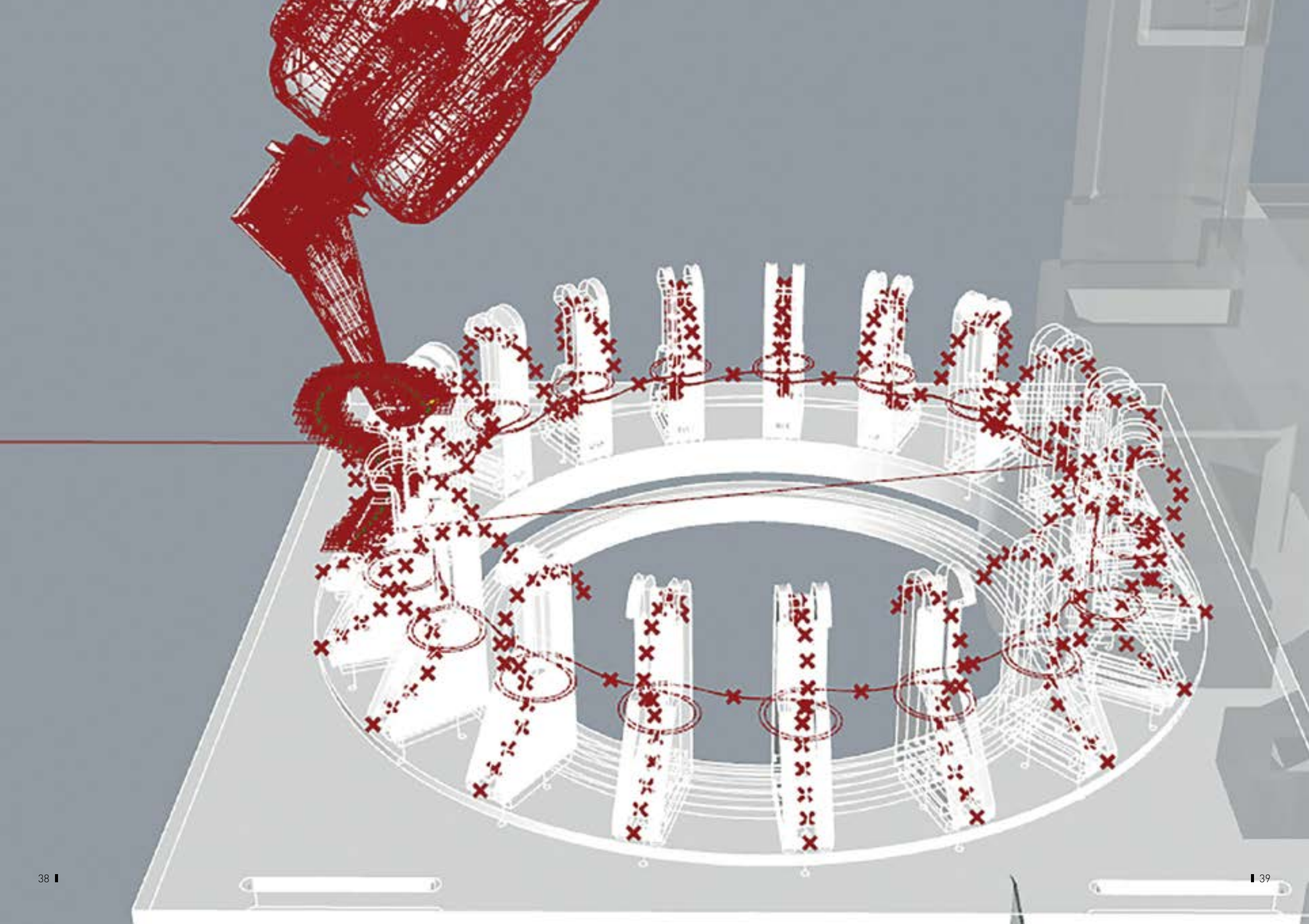
The experimental methods presented here departed from the firm belief and assumption that augmented knit tectonics present a potential for innovative spatial and architectural applications granted by recent advances in material and digital fabrication. By means of programming material properties and controlling material distribution within an architectural artefact, its intrinsic tectonics are no longer fixed, but mutable.

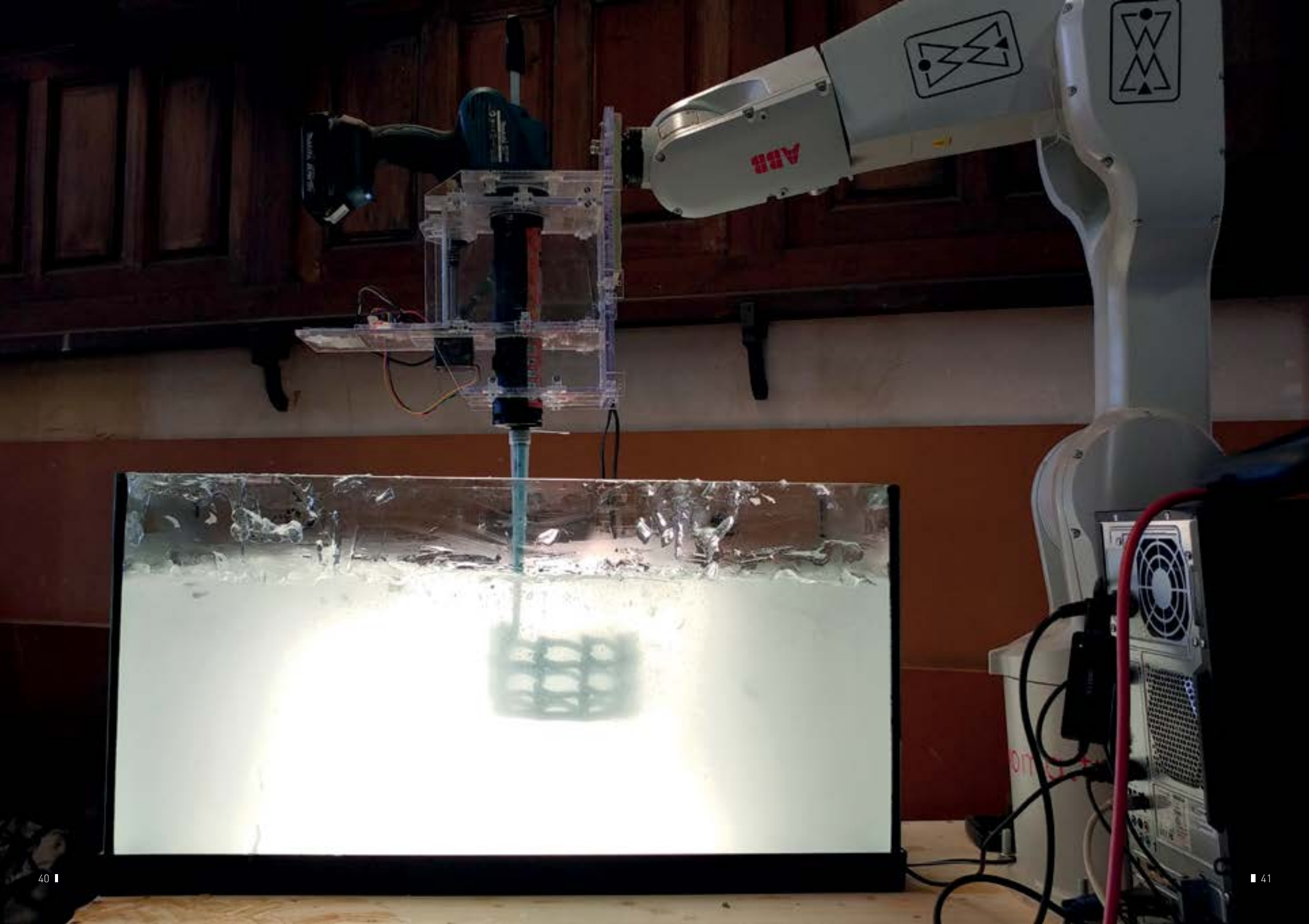
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### Adaptive Material Systems for Thermal Comfort in Architecture Based on Phase Change Materials

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The existence of thermal comfort in buildings, together with the mechanisms that supply it, is an expected quality of contemporary built space, and an undisputed task of architecture to act as a provider of the indoor climate. However, if we were asked to identify architecture's own thermal sensory system, we would have to look beyond architectural components and enter the hidden territory of wall and ceiling, cavities, cellars, and roofs, to find clusters of ducts, compressors, thermostats, valves, switches, and other mechanical equipment, all placed there to sense and quantify the indoor climate and respond to the needs of building occupants. Environmental systems for climate control coexist with the physical structures of buildings, but their performance belongs to the disciplinary field of mechanical engineering (Banham, 1969). In contrast to architectural tectonics, concerned with the principles of the construction of solid matter, the science of thermodynamics and building energy technology operate with dynamic systems in motion – matter and energy flows.

The design opportunities arising from the integration of material systems and thermodynamic processes might lead to profound changes in the way we conceptualise architectural elements as active parts of thermal environments. Recent advances in materials science have given rise to the novel class of phase change materials (PCMs) with an inherent capacity for thermoregulation that, unlike conventional, static building materials, dynamically respond to surrounding temperature fluctuations by storing thermal energy. An entirely new set of design methods that bridges architecture and thermal engineering is required to analyse and incorporate this thermodynamic, phase-change behaviour into architectural design. Still, for such methodologies to extend the notion of thermal comfort beyond utility or service, they need to be driven not only by energy efficiency but by the generative role of energy in organising material systems and configuring their relationships with humans and their environment.

At present, climate control systems are power-driven, with an invisible character that is analogous to the thermal neutrality they create. By maintaining a large, thermally uniform environment, heating, ventilation and air-conditioning (HVAC) technology

uses large amounts of energy and often inadequately addresses the needs of occupants (with e.g. frequent overcooling). Vast interior air volumes are conditioned to their outermost boundaries, regardless of occupancy and beyond the scale of the human body (Addington & Schodek, 2005). The fact that contemporary structures are lightweight and have low thermal inertia only strengthens the tendency of turning building envelopes into thermal barriers that tightly separate the inside from the outside (Moe, 2014). Today's building components, detached from the task of environmental control, paradoxically act more in support of the efficiency of air-conditioning systems than in response to the outside climate and possible energy gains.

With the building sector accounting for approximately 40% of total energy consumption and with rising greenhouse emissions, there is a need to reconsider current building energy practices and methods that provide thermal comfort. In efforts to decrease dependency on fossil fuels and promote renewable energy sources, building professions are steadily adjusting to new regulations (Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings). Future directions in dealing with environmental impacts of the built space should, however, involve radical rethinking of the design of thermal environments in architecture without slipping into normative, vernacular, or technological determinism (Moe, 2007). If energy and thermal qualities were central to architectural design, what would be the material, aesthetic and technological implications of such transformations?

To respond to changing climates and counter the mechanistic logic of current environmental technologies, architectural entities would need to assume a more 'metabolic' role to constitute a sensory system in the extension of architecture's own materiality. A technological shift – from mechanical towards adaptive, material-based systems based on PCMs – could be part of this transformation. Building components infused with dynamic phase-change behaviour can become a regulating medium, able to interact with surroundings and modulate temperatures locally, in proximity to the user. These new capacities of architectural elements to regulate flows and accumulate energy resonate with the thermodynamic conception of architecture that "finds its model not in the industrial machine but in the artificial organism", as argued by Fernández-Galiano (2000). Activating an inert material using a thermally adaptive core allows PCM-based elements to mediate between the built and the physiological space, accommodate the climate and weather variability, and operate in continuity with the larger thermodynamic environment.

So, what exactly is the operating mechanism of PCMs? Diverse naturally occurring and chemically produced substances can be categorised as PCMs because of their capability to absorb, store, and release energy in the form of latent heat during melting and solidification at a certain, predictable temperature. The most widespread PCM is ice, commonly used as a cooling agent. PCMs are a suitable medium for storing thermal energy due to their large phase-change enthalpy – a large amount of heat that needs to be added or released during the phase transition that occurs at near-constant temperature. Having melting point within a desired temperature range, PCMs take advantage of diurnal and seasonal temperature fluctuations to store latent heat: when the ambient temperature rises above the comfort zone, the material melts and absorbs the excess heat; after the temperature has dropped, the material solidifies and releases the stored heat. In this manner, PCMs can undergo reversible melting and solidification cycles without degradation (Mehling & Cabeza, 2008).

An integration of PCMs in building materials and components has been widely researched in the domain of energy technology, and suggests a promising method to decrease the dependency on mechanical systems, reduce and shift thermal loads, and improve the overall thermal stability of buildings (Kośny, 2015; Zalba, Mariin, Cabeza & Mehling, 2003). The two most notable architectural precedents are vernacular igloo dwellings and Dr Telkes' Dover Sun House, dating from 1948 – a pioneering project from the post-war era that utilised solar-thermal energy storage with salt hydrates as an exclusive means of heating throughout three winters in a continental climate. The currently available PCM products span from microencapsulated elements, commonly incorporated into walls and ceilings, to macro-encapsulated, in the form of pouches, tubes, or panels placed in building cavities. However, in recent research PCMs have been regarded as additives that improve the thermal performance of conventional building materials and, with rare exceptions, have remained largely under-represented in architectural design.

Although the primary goal of their implementation has been to achieve energy savings in buildings, PCMs present yet unrealised potential for new design methods that evolve from their thermodynamic behaviour. Current advances in materials science and digital design and production technologies are allowing material systems not only to be designed for specific performance, but open a possibility for materials to become catalysts for novel design expressions (Bechthold & Weaver, 2017).

The experimental investigations presented here aim to widen the range of PCM applications for local thermal regulation in architecture and extend the architectural design agenda with PCMs towards visible, transparent elements for passive indoor cooling. The novel methodological framework connects digital modelling and production techniques with an experimental set-up for thermal cycling, devised to analyse the impact of PCM prototypes on indoor temperatures. In addition to the instrumental set-up, a computational fluid-dynamics (CFD) phase-change model was developed to examine thermal behaviour in detail and inform the future design of prototypes. Following this method, correlations were made between the geometric configuration of PCM containments and their cooling performance, resulting in a series of macro-encapsulation prototypes that functioned as indoor heat absorbers. In these prototypes, PCMs were encapsulated in another durable material (plastic, glass), forming a joint thermodynamic material system with an inherent capacity for thermoregulation.

While the main purpose of encapsulation is to contain PCMs during the liquid phase, properties such as material, size, and geometry are of great importance for visual and thermal perception. Transparent macro-encapsulations that display PCM transformations can vary from opaque to clear, making the processes of thermal adaptation visible, and framed within the design realm on the scale of architecture. The form and spatial distribution of encapsulations, in turn, govern the heat transfer between the PCM and surroundings, and influence how the stored energy is delivered to the neighbouring space and the user. Using digital modelling techniques, the morphology of the encapsulation can be shaped to increase the contact surface between the PCM and the surrounding air (a heat sink) and improve the ability of the material to undergo the phase change (Khan, Khan & Ghafoor, 2016). Thus, the attributes of PCM encapsulation – transparency, geometric configuration, conductivity, and spatial arrangement – are crucial parameters that require careful design considerations in order to reduce melting and solidification times, affect the release and absorption of energy, and communicate the expressive character of the PCM system. Certain geometric typologies, such as three-dimensional dendritic structures, showed outstanding performance in the experiments. Their design corresponds to the logic of growth morphologies found in nature, which emerge and develop in response to energy flows passing through the system (Bejan, 2000). Having a large surface area around a small volume, these branching, vascular spatial organisations can enhance the heat transfer between PCM containments and their surroundings, and contribute to novel, material-based concepts for local thermal regulation in buildings.



The described strategies – based on material, geometry, energy, and aesthetics – can redefine the role of environmental technologies in architectural design and help overcome the strict separation between the physical substance of buildings and their service systems. From the perspective of the physiology of the human body and the cultural and social significance of thermal environments, energy-exchanging material systems have the capacity to outgrow their role in managing thermal environments and become expressive elements of design (Heschong, 1979; Abalos, Sentkiewicz & Ortega, 2015). By radically questioning the notion of materiality in architecture and rooting it in thermodynamics, these integrated design methods can renew aspects of architectural design related to thermal comfort and bring the vital, formative principles of energy to the forefront of the architectural design agenda.

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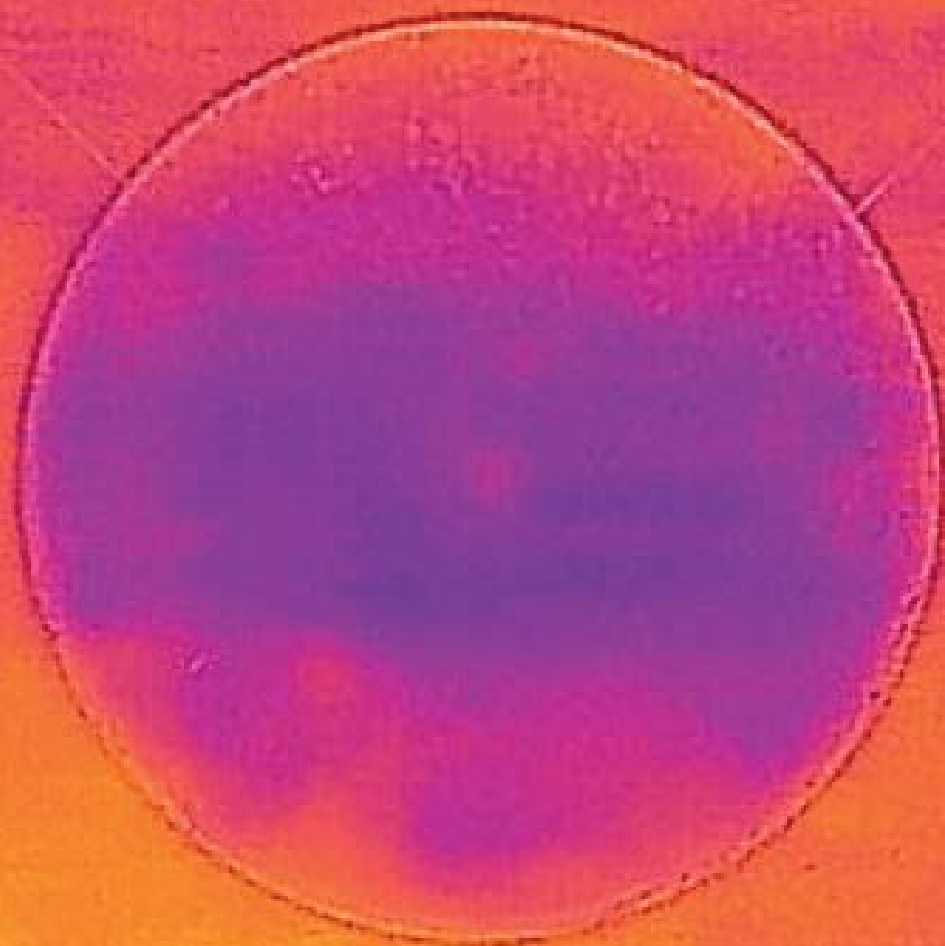
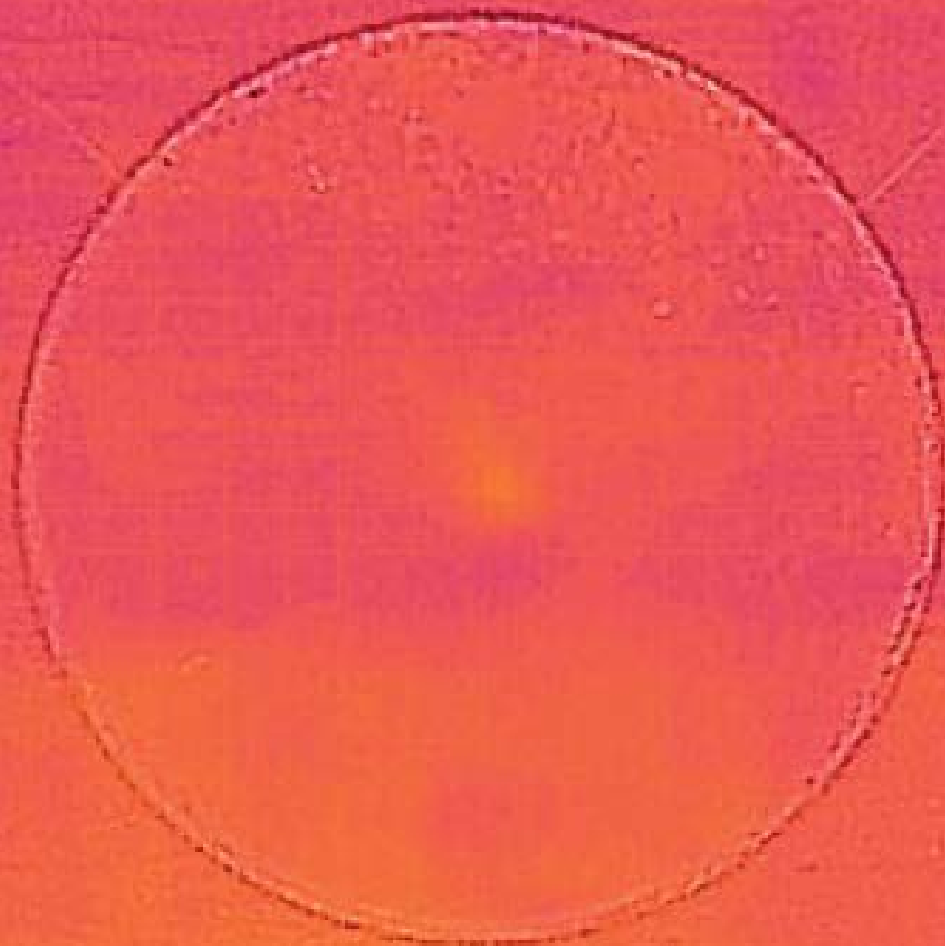
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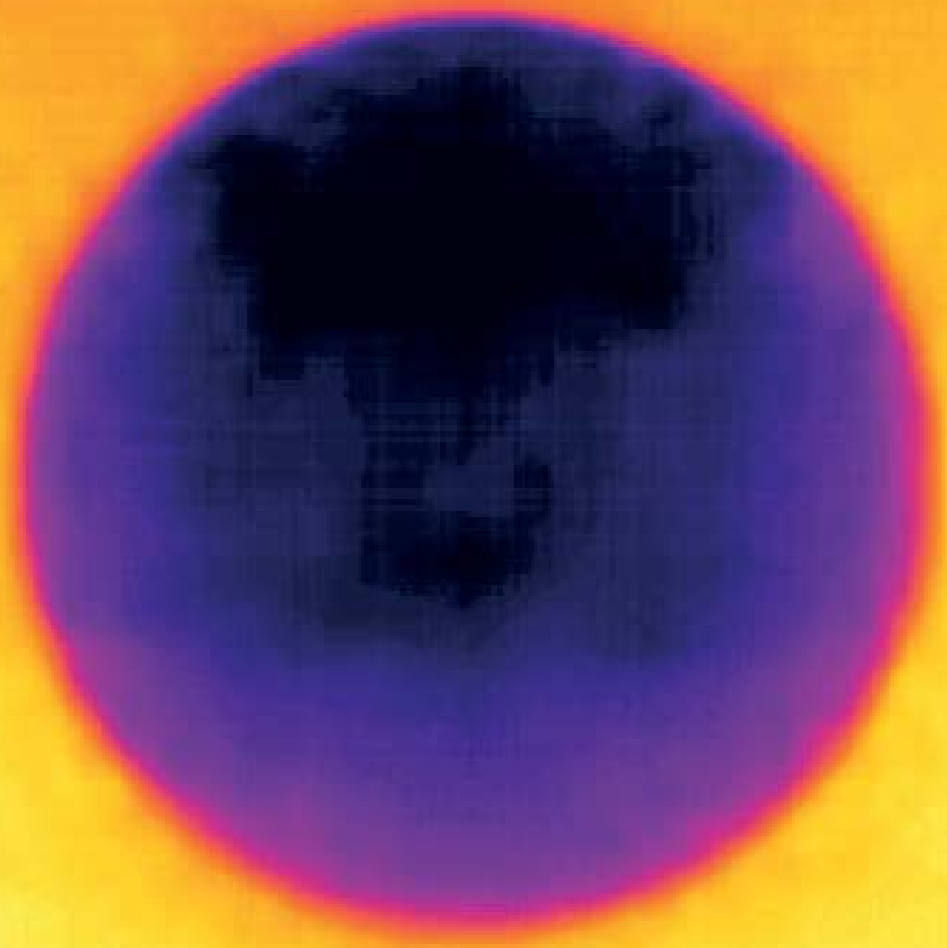
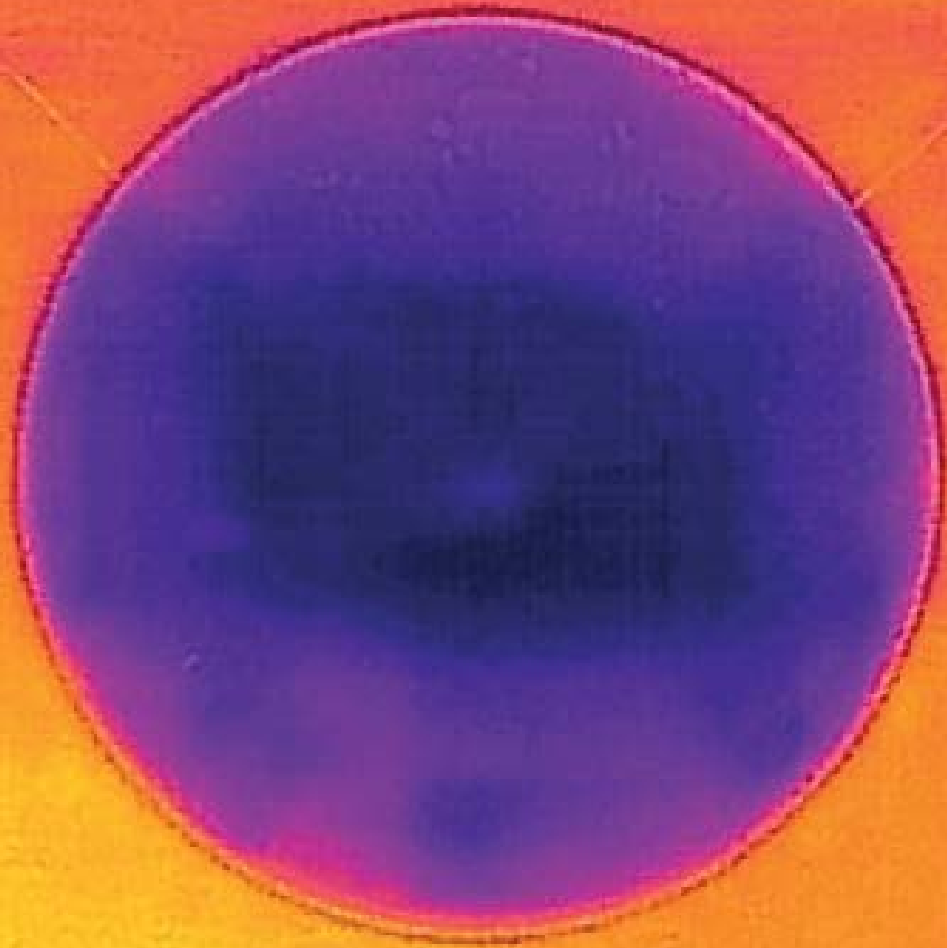
## THE SCALE OF THE BUILDING

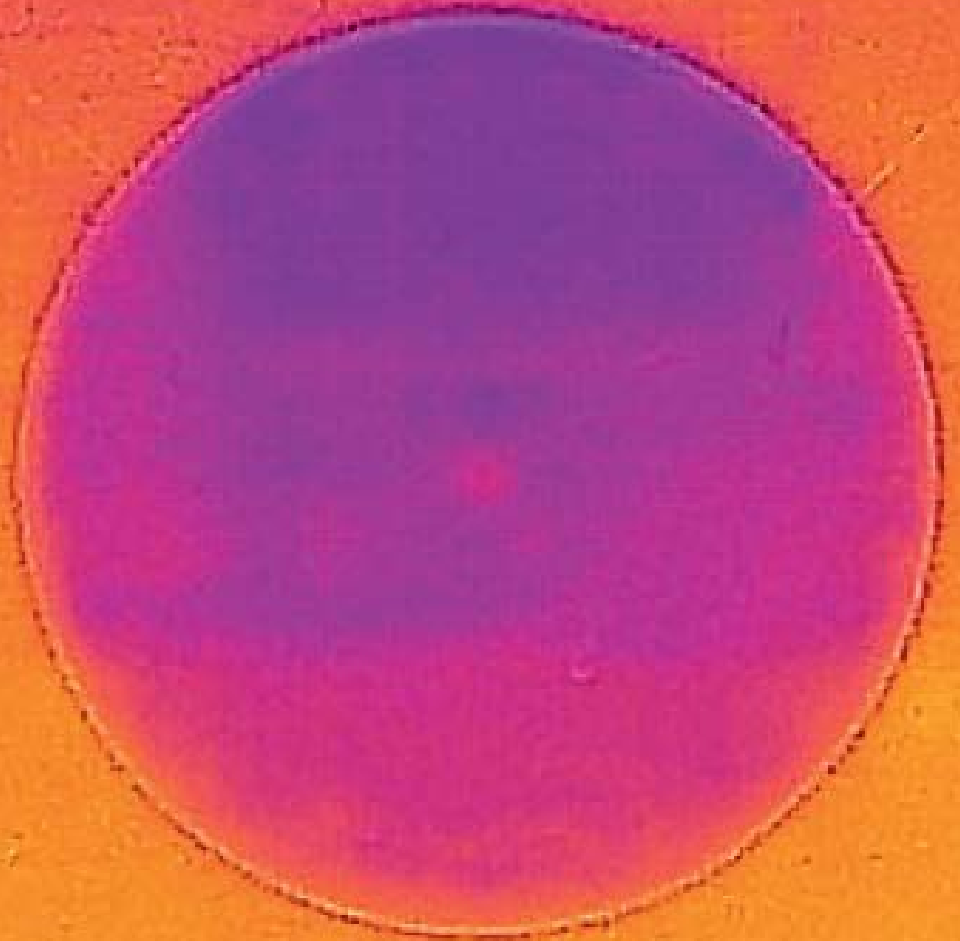
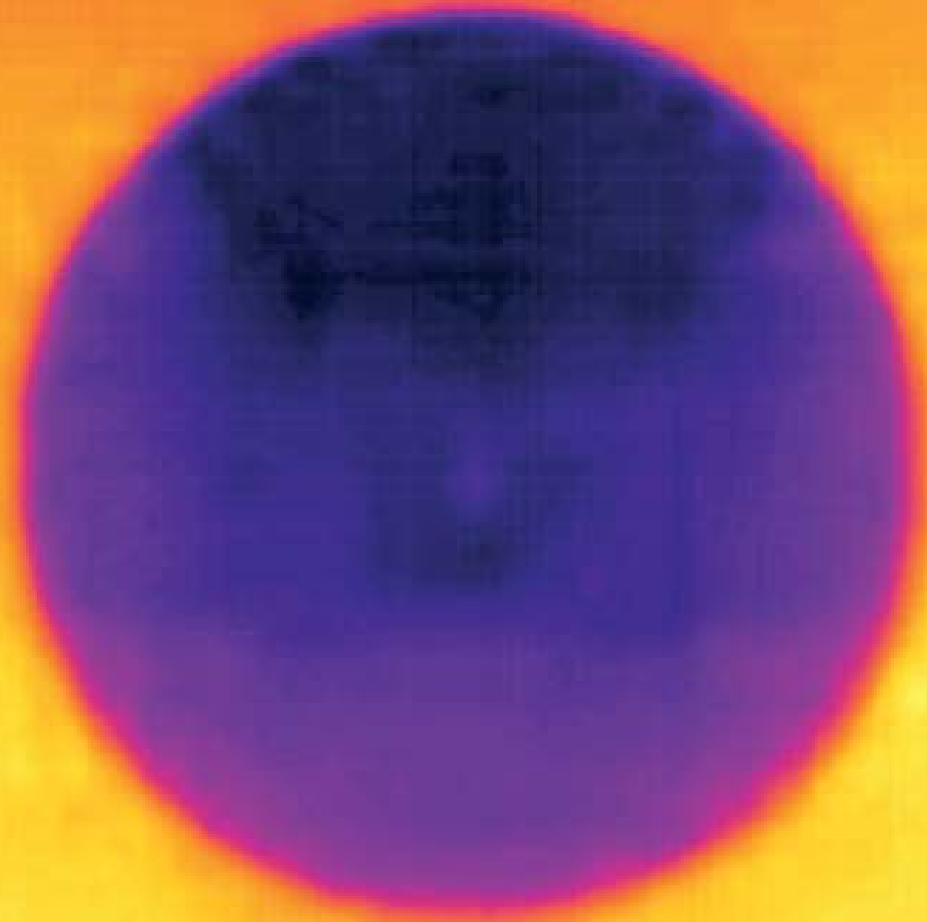
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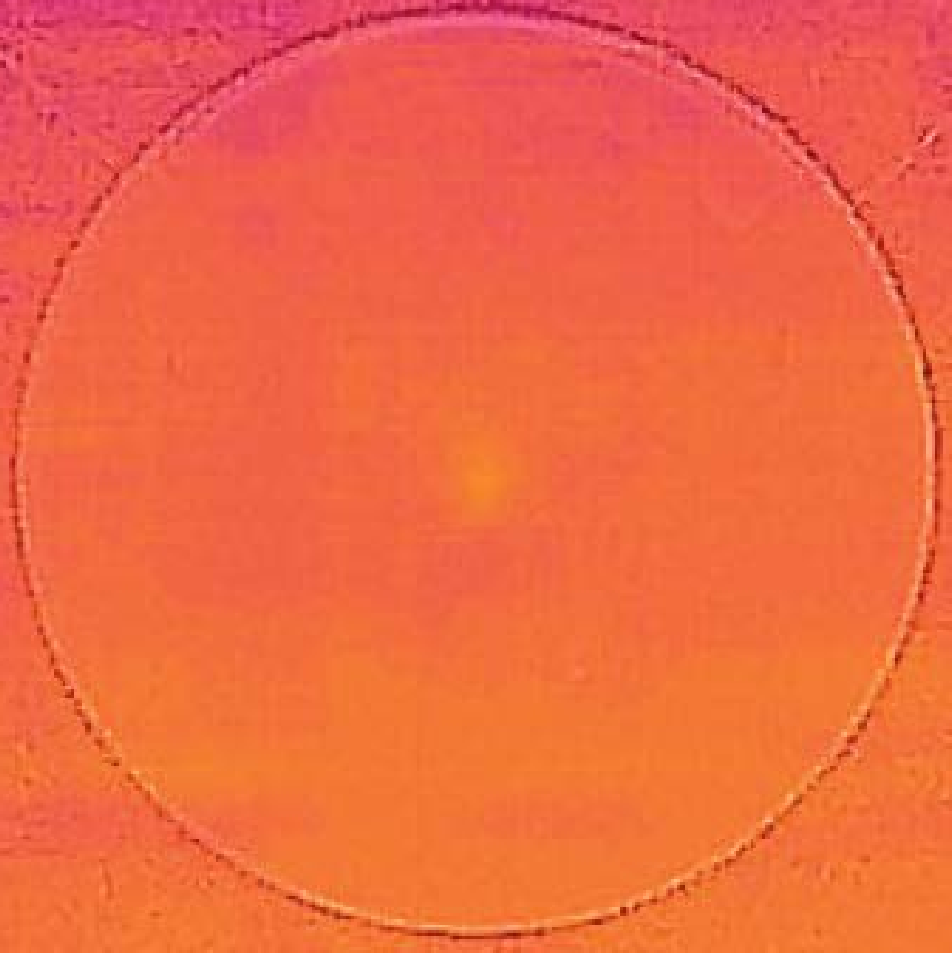
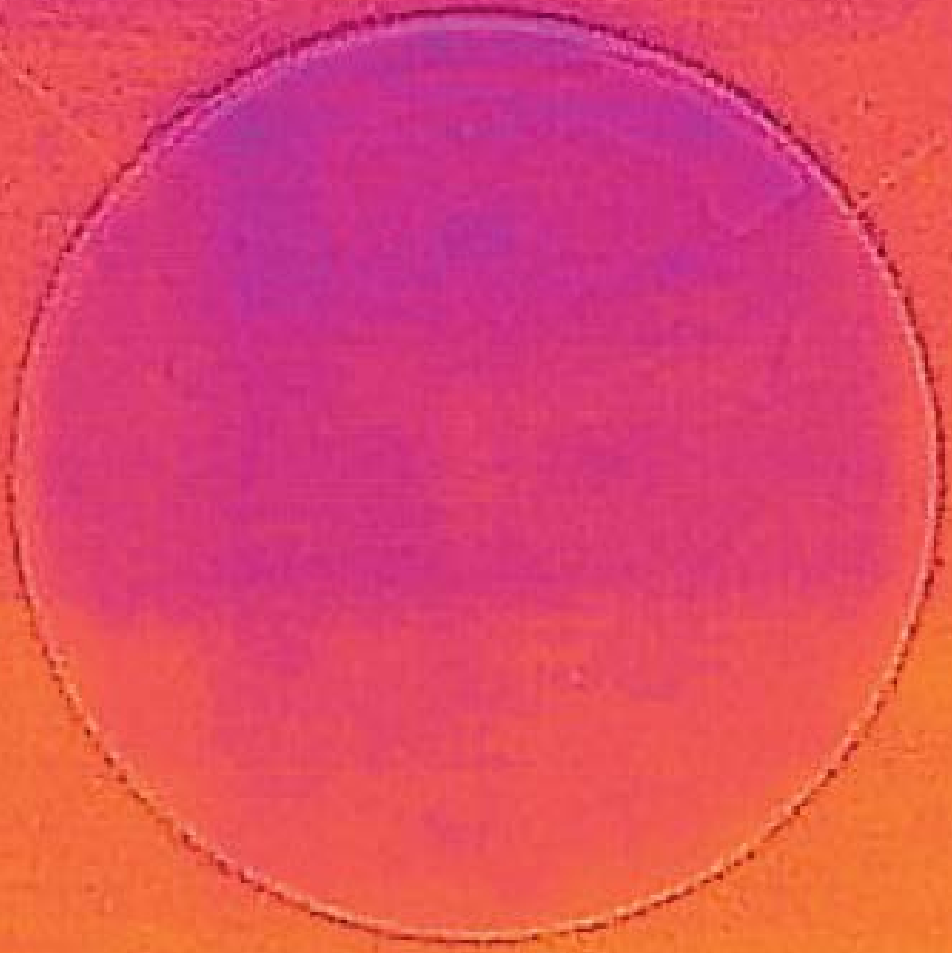
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DESIGNING ADAPTIVE AND  
RESPONSIVE TEXTILES  
(TEXTILE AND FASHION DESIGN)

Soft Embodied Architectures: Towards a  
Hybrid Embodied Design Ideation Method for  
Soft Architectural Design

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The way architects work with materials differs significantly from approaches in other design disciplines. In fashion and interaction design the engagement with the material during the design process is more direct, allowing designers to experiment fully with their prototypes using their whole bodies in context (Blaisse, 2013; Ross & Wensveen, 2010). In architecture, by contrast, the relationship with materials is often relegated to the scale of the model, making it difficult for architects to acquire knowledge through first-hand experiences with materials at one-to-one scale. Sattrup points out that architects are “rarely [...] directly building their own work, and much of the analytical and projective design process is executed via the symbolic representations of space through geometry” (Beim & Thomsen, 2012, p. 105).

While experimentation with soft materials in the creation of artefacts is a common practice within the architectural design field (Wærsted, Lenau & Brandt, 2014), the use of embodied design ideation (EDI) methods that allow knowledge to be gained through first-hand experience is rarely addressed. EDI methods make use of the body and its senses to support the early phases of a design process, wherein the body plays different roles depending on the designer’s motivation, e.g. prototyping with materials, analysing body movements, or communicating design concepts or ideas to others (Wilde, Vallgård & Tomico, 2017). An embodied approach such as this involves the challenge of change of scale; whereas one comes with a challenge that is the change of scale. Whereas the above-mentioned EDI methods have been used to design from the body to the body (fashion design and interaction design), the present inquiry addresses the challenge of designing soft architecture by means of the body, from the body, to the building.

By using an EDI method, architects are able to engage with materials in a more detailed way and dynamically shape through several iterations which are supported by processes of reflection (Schön, 1983). Consequently, EDI methods could contribute to open up for novel ways of ideating textile architecture, e.g. from a human-centred perspective. Moreover, this perspective can provide dancers, choreographers,

embodied interaction designers, and architects with methods from other disciplines through collaborative design processes.

From a textile-design perspective, the dynamic qualities of textiles, manifested through the interaction with the body, trigger folding elastic and transparent transitions that could shape new ways for architects to interact with materials. Through this lens, the widely known concept of 'textile architecture' is redefined as a soft and embodied architecture, making a difference in the way textile materials are explored and applied within architectural design processes (Schillig, 2009; Pišteková, 2017). 'Soft Embodied Architectures' differ from the traditional way of using textiles in architecture, such as tensile membranes or composite textiles that behave in a similar manner to hard materials. (Ramsgaard Thomsen & Bech, 2011). Here, the notion of 'soft embodied architectures' relies on the relationships that emerge from the interaction between human and non-human agencies such as the body, the material, and the context (Latour, 2005). This set of relationships gives room to soft body-space entities with different dynamic qualities, such as gradients of transparency, elasticity thresholds, and material foldability.

To expand the prototyping design space, the use of motion-capture technology would enable architects to map out the soft body-space entities in the digital realm. Such a hybrid process would provide the formation of digital geometries that can be further explored using procedural modelling software (Castán & Suárez, 2017). By combining an EDI method with motion-capture tools such as Kinect sensors, a hybrid process would emerge. Such a process could lead to the design of a hybrid EDI method that combines embodied and digital outputs, connecting soft spatial experiences with digital geometries. Thus, contributing to bringing insights into soft, embodied architectural design.

Different examples show the process of ideating soft architecture by means of the body. 'The Spatiality of Textiles from an Embodied Perspective' illustrates the transitional state of textiles ranging from materials worn on the body to textiles as a soft, embodied space. Three dynamic and spatial qualities can be envisioned based on the relationships between the textiles, the body, and the context: the spatiality of billowing soft spaces, the spatiality of folding soft spaces, and the spatiality of deformable soft spaces. The first spatial quality enables the inhabiting of a soft volume in motion to be experienced as well as; how the textile behaves when it interacts with the body and the wind. The second spatial quality shows how the subtlety of a transparent

textile allows the participant to devise a space that is inside and outside at the same time. The third spatial quality relies on the concept of a transitory state in relation to the elasticity of the textile, allowing the participant to shape the amount of light and take up room by stretching the textile.

'Soft Embodied Morphologies: Bridging Physical and Digital Realms' demonstrates the potential of using motion-capture technology to map out the spatial qualities found in an experiment, with the aim of expanding upon the design possibilities and articulating the first iteration of a hybrid EDI method for soft architectural design. Embodied design outputs and digital design outputs open the door for hybrid design processes. The digital design outputs propose two digital explorative design strategies: the shell structure and the skin structure. The shell structure allows the volumetric potential of the geometry to be explored, and the skin structure enables surface exploration.

'Layering Up Soft Materiality: Exploring the Design of a Hybrid EDI Method for Soft Embodied Architectural Design' describes a collaborative process with architects and dancers to explore the opportunities and limitations of using an EDI method and motion capture technology for soft architectural design. By collectively exploring three different materialities in a situated activity, an embodied design principle emerges. 'Layering up' different fabrics through body interaction offers a dynamic way of ideating soft, collaborative architecture, not only supporting the design process but inviting a more dynamic use of such spaces. The digital data obtained by a single Kinect sensor are fragmented geometries that show the potential of connecting the experience of ideating a soft embodied space to its digital images

Finally, 'Soft Embodied Architectures: Towards a Hybrid EDI Method for Soft Embodied Architectural Design' introduces a novel hybrid embodied design ideation process that contributes to expanding the architectural design methodology. Through a custom-made interface, made of soft and hard materials, an elastic space can be explored through choreographed body movements. The interaction between the body and the elastic interface provides room for a new, soft spatial entity that produces a collection of form expressions, ranging from subtle surface modifications to more prominent deformations. Such form-giving processes are captured by three Kinect sensors, offering a complete geometry that is connected to the spatial experience. Such geometry could be conveniently manipulated to create future soft architectural scenarios, such as deformable modular building units, façade elements, or wall divi-



ders, validating the digital toolset as a new way to ideate soft architectural design.

Collaboration is an important aspect of the design process of 'Soft Embodied Architectures', which requires the involvement of various forms of expertise in order to articulate a hybrid embodied design ideation approach for soft architectural design. Dancers and choreographers are experts in expressing themselves with their bodies and performing improvised body movements; their role as facilitators to support the application of an EDI method would provide architects with a more immediate engagement with the embodied explorations.

To conclude, Soft Embodied Architectures aims to expand our understanding of textile architecture towards a concept of soft, embodied architecture by exploring textile materials in an embodied way. The articulation of a hybrid embodied design ideation process for soft, architectural design further develops the temporary spatial qualities afforded by billowing, folding, deforming, and layering soft materials in relation to the body. Such temporary, soft body-space entities can be additionally extended into the digital realm using procedural modelling software. As a result of building a hybrid design process, an emergent design space is created that opens the door for novel ways of ideating soft architecture by:

- (1) Allowing architects to engage with textiles more experientially, engaging their bodies and full ranges of senses, enabling the discovery of soft spatial and dynamic qualities through the agency of the material, the body, and the elements of the context.
- (2) Connecting temporary, physical spatial experiences with their digital geometries by capturing such experiences in real time. Such a hybrid process allows the design possibilities to be expanded by exploring the surface and form of the geometries.
- (3) Providing new ways of collaboration between textile designers, interaction designers, architects, dancers, and choreographers. Such collaborative experience enables architects to gain direct insights into the future uses of such spaces.

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## THE SCALE OF THE BUILDING

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### Smells: Olfactive dimension in designing textile architecture

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A building is encountered; it is approached, confronted, related to one's body, moved through, utilised as a condition for other things. Architecture initiates, directs and organises behaviour and movement (Karandinou 2013). What role does smell has in these functions and agencies? How can smells re-define the concepts of space in terms of spatial continuity, enclosures and openings? How can smells affect the spatial relationships within spaces or adjacent. How can movements through the space be dynamic or inactive when explored through the sense of smell? How can the concepts of windows, doors, pillars, ceilings and floors be understood and translated using the sense of smell? When these spatial concepts are juxtaposed with the olfactive perception of a space, there is an understanding of the boundaries that are invisible within a space and yet significant to either open up the spaces or hinder the continuity of the movement.

The ambiguousness of textiles leads to their having almost no form, although these are generally present in certain measurable dimensions - texture, colour, pattern, weight, hand feel and drape and these are the qualities that a designer can design with. However, the materiality of a textile is transformative not only in its tangible and physical presence, but also in the language of textiles; verbal, visual and auditory. Through colours and yarns, a pattern is designed. Conventionally, this textile is then attributed with certain qualities that relates to its purpose, and these do not go beyond this purpose and are classified by textile language in relation to it. However, if the materiality is taken as a method or approach (Olsen 2016), this textile could be imagined interchangeably to be something else, opening up the possibilities of what its character could be. As suggested by Bogart et al. knowing what a door is and what it can do limits oneself and the possibilities of a door. Upon being open to its texture, colour, size and shape, it can become anything and everything (Bogart and Landau 2012). Although, references to the olfactory language of textiles is missing. Yet this section, tries to bridge this gap through dialectic interactions between textiles and smells. The dynamic nature of smells can be related to the lightweight materials. Smells are volatile without any particular form of moving molecules, constantly changing the intensity and flow of smells with the passing time, flow of air and forms

of space. What would smells feel like if they had the textures of textiles? How would textiles unfold if they have the dimension of smells? The transparency in textiles gives a space a soft boundary, although this can be overridden while one walks through the soft and fluid textile, tactility of the material is rather alluring. Through the touch, material unfolds the smells. Transparency becomes the texture of the smell. Smells surround and envelops the body as a textile would, creating a feeling of familiarity and therefore the comfort of being surrounded with smells. 'Smell is the sense that interrupts the progress of rational thought; it stands in ambiguous relationship to the tactile proof offered by touch' (Arning 2006).

Smells could be understood as a design material and can be applied in many scales. Investigating textiles and architectural spaces as containers of smells, the design explorations can examine the material as a matter and performance in relation to the body and space. Textiles can be considered to be tangible expressions, that unfolds the smells through interaction; this interaction is through the body at different scales, either through touch and gestures of hand through the textures of the textiles, or the movement of the body in space, both explore the qualities of smell.

While exploring olfactive interactions one focuses on tactile senses as beyond visual perception and representation. Through the sense of touch, triggered by bespoke textile objects, smells had been revealed, activated, and disseminated in a space. Other experiments investigated the activation of smells in a space through the movement of a dancer's body, who improvised her movements with the textile objects that became the source of smell in the space. Changes in the flow and intensity of smells and movements over time added another layer and depth to a multi-sensorial experience.

Performance as a design method could here be used to investigate spatial elements in a space and the movement of the body in relation to the smells in a space is used for exploring spatial concepts. Concepts from dancer's choreographies of walking the space, or working with the objects in relation to body and space are re-written keeping smells in the focus. This method of performance brings in the elements of everyday routines and everyday objects in an interesting context where the interactions in the space with these routines and objects are questioned with regard to smells.

As a method for interacting with smells in a space, the movement of the body could be used, where the interaction between body movement and smell express the spatial interaction of the smells. Such movements may be similar to smells in space, as both

are ephemeral and exist in time in similar ways. When compared, the dimension of time does not exist in visual arts. Changes in the flow and intensity of smells and movements over time adds another layer and depth to a multi-sensorial experience. Interaction with smells in a space is like being a spectator in a state of being and tracking the movements of smells in its duration as a passing time. Through the improvisations of movement, created expressions of smells in a space bring in the conscious dynamic state of smells into being.

Methodologies for investigations can also include additive and subtractive methods of smells, whereby textile materials can be applied as absorbers and reflectors, ('Absorber' refers here to materials that can absorb smells until a saturation point, 'reflector' identifying smell absorption of textile materials up to their respective saturation points, properties that can be controlled with the help of nanotechnology). How can smells be activated in a space? How can they be represented and interacted with? In this research, haptics are explored as one of the methods of interaction with smells through textiles. While exploring olfactive interactions in relation to the body in space, this research focusses at the tactile sense as a way of representation. This is also referred to in this research as spatially near to body scale explorations. Through the sense of touch, this research also investigated ways to reveal, activate, and disseminate the smells in a space. The textiles and textile objects were designed for interaction. The smells have been purposely added to textile materials that did not possess any inherent smells. Through physical interaction of these textiles, smells are activated, released and diffused in a space. Through the action of touching, for example either by pressing, rubbing, crushing, peeling, folding or unfolding, ways of activating and disseminating smells were investigated. These methods of activating smells were derived through the explorations of various actions.

Investigating textile materials to be potential smell absorbers and reflectors, the term 'absorber' refers here to materials that can absorb smells until a saturation point by a simple technique of wicking. 'Reflector' is a term referred here to the smell absorption of textile materials up to their respective saturation points. With the help of nanotechnology these functions of absorption and adsorption can be designed to the textile materials. With an aim of using subtractive methods of absorbing the smells and modifying the smells or 'reflecting the smells' from near environments using textiles as a medium, these textiles could be used for designing spatial environments.

Designing with non-visual attributes challenges traditional ways of perception and representation in architecture and textile design. Results from such investigations can lead to a wide width of applications such as textiles for fashion, sports, architecture, spatial design, urban designing etc. Future research areas could be identified in sub-categories of these domains that are structured as smells / textiles, smells / body, and smells / space. Under each category, the potentials of using smells as a design material, attribute or a dimension would be a catalyst to change common ways of designing. The results and outcomes can open up an olfactive dimension to the discipline of design and architecture but also for scientific research to developing methods with smells as a design material.

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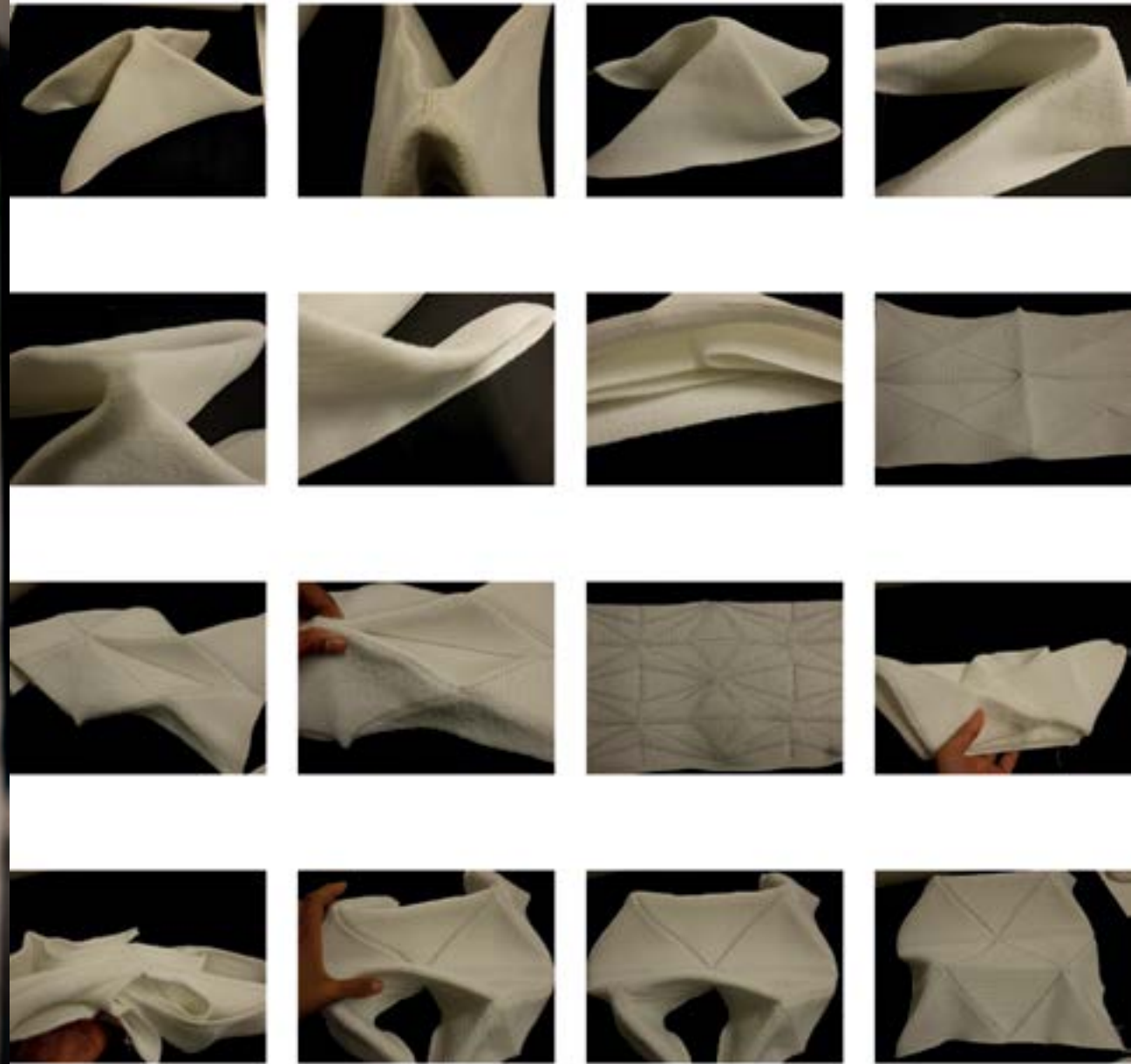
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DESIGNING FOR ADAPTIVE  
AND RESPONSIVE  
FAR-FIELD INTERACTIONS  
(TEXTILE INTERACTION DESIGN)

## Utilising Textile Microbiomes in Fibre-based Architectural Composite

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Microorganisms and eukaryotic organisms, such as fungi, are in constant exchange with their environment. They absorb nutrients which are metabolised into energy for cell multiplication and, in some cases, even structural by-products such as nanocellulose or chitin fibres (Gow & Gadd, 1995). These intrinsic characteristics can be utilised as novel matrices for composite materials and contribute to the advancement of materials for design and architecture. Fibrous scaffolds can in this context provide a suitable substrate for a specific textile microbiome. A synergetic effect emerges through the interaction between the microorganisms and the textile which is expressed through active and adaptive properties and/or changes of structural behaviour.

Composite materials generally owe their outstanding properties to an intelligent combination of two or more materials within one material system while their individual constituents remaining distinct (Hull & Clyne, 1996). The emerging properties, harnessed through this combination, balance out the weaknesses of individual materials while multiplying their strengths. Generally, a composite consists of a continuous phase – the matrix – and a discontinuous phase – the reinforcing element of the system. The discontinuous phase or reinforcement is usually comprised of a fibrous or filamentous material that accounts for the resistance to tensile forces, while the matrix provides compression resistance (Netravali & Pastore, 2014). The combination of the two mechanical characteristics in one system delivers an exceedingly efficient material, allowing for a high level of customisation and control through targeted material selection.

The notion of composites has recently centred primarily on advanced composites, such as carbon or glass fibre-based materials. The field, however, encompasses a very wide spectrum of materials, ranging from naturally occurring, cementitious materials to living materials such as bone or skin (Davies, 2016).

The use of natural composite materials such as wood or reed for construction is deeply embedded in architectural culture, and the techniques to improve their performance and spectrum of applications have constantly evolved (Hofmann & Smyth,

2013). The first man-made composites most likely emerged from the idea to improve certain characteristics of existing natural materials by adding a secondary material. An early example of this process can be found in straw-reinforced bricks dating back to ancient Egyptian cultures (Campbell, 2003). A similar but more advanced example is ancient archery equipment which is manufactured from laminated wood and different inlays of natural fibres (Gay & Hoa, 2007).

Contemporary, advanced composites are highly engineered materials usually employing glass or carbon fibre as a means of reinforcement. Combined with high-tech resins, the materials deliver unprecedented properties in regards to weight, stability, and resistance, outpacing conventional construction materials such as metals or plastics (Bucquoye & Beukers, 2002). Their drawback, however, is their energy-intensive, time-consuming, and labour-intensive production, as well as their dependency on petrochemical resources. The increased applications across many fields at the same time pose the crucial question of sustainable recycling strategies for composite waste materials, which has not yet been answered sufficiently and holistically (US Department of Energy, 2015).

Sustainable raw materials, such as natural fibres or bio-derived resins, provide a viable alternative to petrochemically derived materials (Netravali & Pastore, 2014). This field, dubbed 'green composites', has recently gained increased attention and is evolving quickly. Although green composites cannot fully substitute advanced composites, bio-derived materials promise a reduced environmental impact and a potentially bio-degradable alternative. The approach of sustainable composites is to extract, process, and refine naturally grown or occurring materials and to combine them in an intelligent way, in a manner similar to the ancient Egyptian straw-reinforced bricks described earlier. This comparison does not apply exclusively to green composites, but similarly concerns the general prevalent paradigm of composite manufacturing. Raw materials are being extracted from nature, refined, and successively combined, rendering a composite.

A new perspective on natural composites can be gained by not merely extracting resources from nature but generating new materials through nature. This axiom triggered the investigation for novel strategies for biologically active composites. The approach centres around the idea of utilising microbiological mechanisms, as described at the beginning, and to harness their intrinsic behaviours to influence textile material systems.

As indicated in the beginning, microorganisms are able to generate a wide range of by-products and trigger biochemical reactions upon external stimuli, which can potentially be harnessed for composite matrices (Lee et al., 2014). Specific fungi, for example, develop a chitinous fibre network called mycelium, which serves as their means to source nutrients and propagate (Stamets, 2005). This network is able to permeate the medium it is cultivated on, binding together the granular substrate hence influencing its structural performance (Travaglini et al., 2013). The medium can thus consist of a wide range of organic waste or agricultural by-products. Furthermore, the process does not rely on any external source of energy, such as sunlight or specific nutrition, allowing for a very local and sustainable method to generate materials (Benjamin, 2017). This natural process has gained increased attention in recent years, and is meanwhile applied as a sustainable alternative to Styrofoam products. Another example is a commonly used bacterium in food production, *acetobacter xylinum*. Part of its natural metabolism consists of the generation of nano-cellulose fibres, resulting in a hydrogel-like material gradually accumulating on the surface of the culture. This by-product recently has found use as a leather substitute for the fashion industry (Hemmings, 2008). These examples show the disruptive potential of applied microbiology for a wide range of fields. Harnessing biology through a hybrid technology of biotechnology and material engineering has been shown to be a valuable approach and a rich, yet under-explored field to be investigated. Emerging technologies and processes developed through the synthesis of these fields increasingly uncover new bio-materials, which could potentially contribute within the architectural domain.

Current biotechnological systems are mainly developed for the food or pharmaceutical industries. Breweries, as one example, draw upon experience and design and process iterations dating back thousands of years. Compared to that, the relatively new field of applied biotechnology in the context of material design has only been in the making for a mere 15-20 years. This poses many challenges, as biotechnological systems and processes need to be adapted and redesigned to serve this new purpose. These processes, derived from biotechnology, contrast starkly with our contemporary modes of manufacture in the context of the built environment, and call for a new aesthetic of production that can inform a novel branch of processual, reactive, and time-based architecture. Concomitant to these developments, prevalent architectural norms and conventions would have to undergo significant changes. At the same time, a novel taxonomy of microbiological by-products and functions needs to be established in order to match the challenges and issues of the built environment to the

solutions biology can offer. Another challenge inherent to the use of biotechnology in the architectural domain is scale. Microbiological processes, as the term suggests, take place on a micro scale. Architecture, however, operates on a macro or mega scale, which raises the question of how to bridge this scalar gap. In order to apply a microbiological system to an architectural scale, a specific medium has to be selected to 'host' the microbiome. This alludes to the issue of the bio-receptivity of certain materials (Cruz & Beckett, 2016). The prevalent material culture in the built environment is rather focused on impeding the development of any form of microbiological activity for reasons of hygiene and durability. This status quo, however, may well be challenged in the light of recent developments. By embracing microbiological agency within the built environment, a new symbiosis could emerge between high-tech materials and complex biological processes, contributing to a reconsideration towards the contemporary notion of building materials.

In this respect, spatial textile scaffolds and/or composite materials offer a suitable platform for such experiments. Textiles inherently possess many properties, such as porosity, increased surface area, and hydrophilic characteristics, which can be furthermore engineered to foster a synergetic effect between fibres and microorganisms. Recent technological advances within robotics, simulation, and design methods (see for example Knippers & Koslowski, 2017; Doerstelmann et al., 2015) made a case for novel aesthetics and efficient, textile-based material systems which can potentially also be harnessed as a platform to explore the notion of active microbiomes within the field of architectural design. The textiles can thus serve as host materials for such microorganisms to propagate and deposit a second biologically active material layer on the fibrous system. These material systems demand a detailed investigation into the relationship between a microbiological community and a fibrous medium, which is determined by a variety of factors. By exploring three different scenarios with distinct microorganisms, their specific activity and contribution within a textile system was observed and analysed. For each microorganism, a series of fibre types and treatment methods were explored in relation to the demands of the microorganism in terms of milieu, fibre topology, and environment. Once the fibres were successfully colonised, the behaviour of the textile system remained unchanged until the organisms were actively contributing to the composite with their distinct behaviour. The biological activity, in its most tangible form, expressed itself in a change of structural behaviour which accounts to the gradual deposition of materials such as nano-cellulose or chitin on a micro scale. Through this process, a multi-hierarchical bio-derived composite material was established. It could be demonstrated that the

global behaviour of a macro-scale textile structure can be influenced by biological activity on the nano and micro levels. Besides increasing the structural performance, the hybrid material, comprised of a textile component and a living entity, actively responded to environmental stimuli, and can thus be understood as a time-based and a reactive material. In contrast to common forms of electronic, chemical, or mechanical means of activating textile materials, the strategy incorporated in this research proposes to harness biology's intrinsic adaptiveness and responsiveness for novel fibre-based composite materials.

It is important to note that the developed materials do not stand in direct competition with advanced composites in regard to their performative mechanical characteristics. The highly engineered, advanced synthetic fibre technology and resins still outpace natural alternatives in many ways (Dittenber & Gangarao, 2012). Therefore, the aim is not to approximate the mechanical properties of advanced materials, but to introduce another layer and perspective on the notion of performance within the domain of composites. This novel performative concept is constituted through the distinctive reactivity, resilience, and emergence fostered by intelligent biological systems.

Recent advances in the field of biotechnology, especially in the discipline of synthetic biology, mark a historic paradigm shift in our understanding of and interaction with biological systems (Baldwin, 2012). The ability to directly interact with the genome of a microorganism adds another complication to inherently complex biological systems, and shifts the engagement with biology from merely passive and observational to an active, creative position. While it is crucial to also consider the ethical implications inherent to this new technology, it can, if deployed in a responsible way, offer a wide range of possibilities in the context of the project. The behaviour and by-products of microorganisms can be manipulated through the means of synthetic biology to respond to certain environmental stimuli, such as light or chemicals, and self-regulating cell systems have been demonstrated (Ellis et al., 2011). Moreover, many of these examples constitute established practice within the pharmaceutical and food industries, while the technology continues to develop at a fast pace. With the rise of synthetic biology, which understands biological systems as computing entities to be reprogrammed and assembled to run specific DNA-based programmes, the convergence of the fields of biology and computation became inevitable. At the same time, material design, as well as architecture, is meanwhile absolutely dependent on computational systems. The two described approaches, then, are not yet compatible. However, as a gradual convergence of these fields, unified by their intrinsic and in-

creasing need to process information (Wiener, 1961), becomes ever more noticeable, calls for suitable, unified approaches and interfaces, as well as congruent systems and languages for a future transdisciplinary workflow, increase in number.

Working with living organisms generally poses various challenges related to culturing, incubation, material consistency, and performance, but also opens up new ways to think of materials in regard to their sustainability, processing, and promising aesthetic concepts related to it. Spatial textile structures can thus serve as a medium and interface for a new class of bio-receptive building materials. Embedded intelligent biological mechanisms within fibrous systems offer a novel trajectory for the design of future composites. They actively respond to their environment through biological metabolism and harness the inherent characteristics of living microorganisms. This paradigm shift within the field of material design is fostered through advances in the areas of biology, computation and architecture. The approach advocates for applied interdisciplinary knowledge generation while embracing the inherent interdependencies of scientific disciplines.

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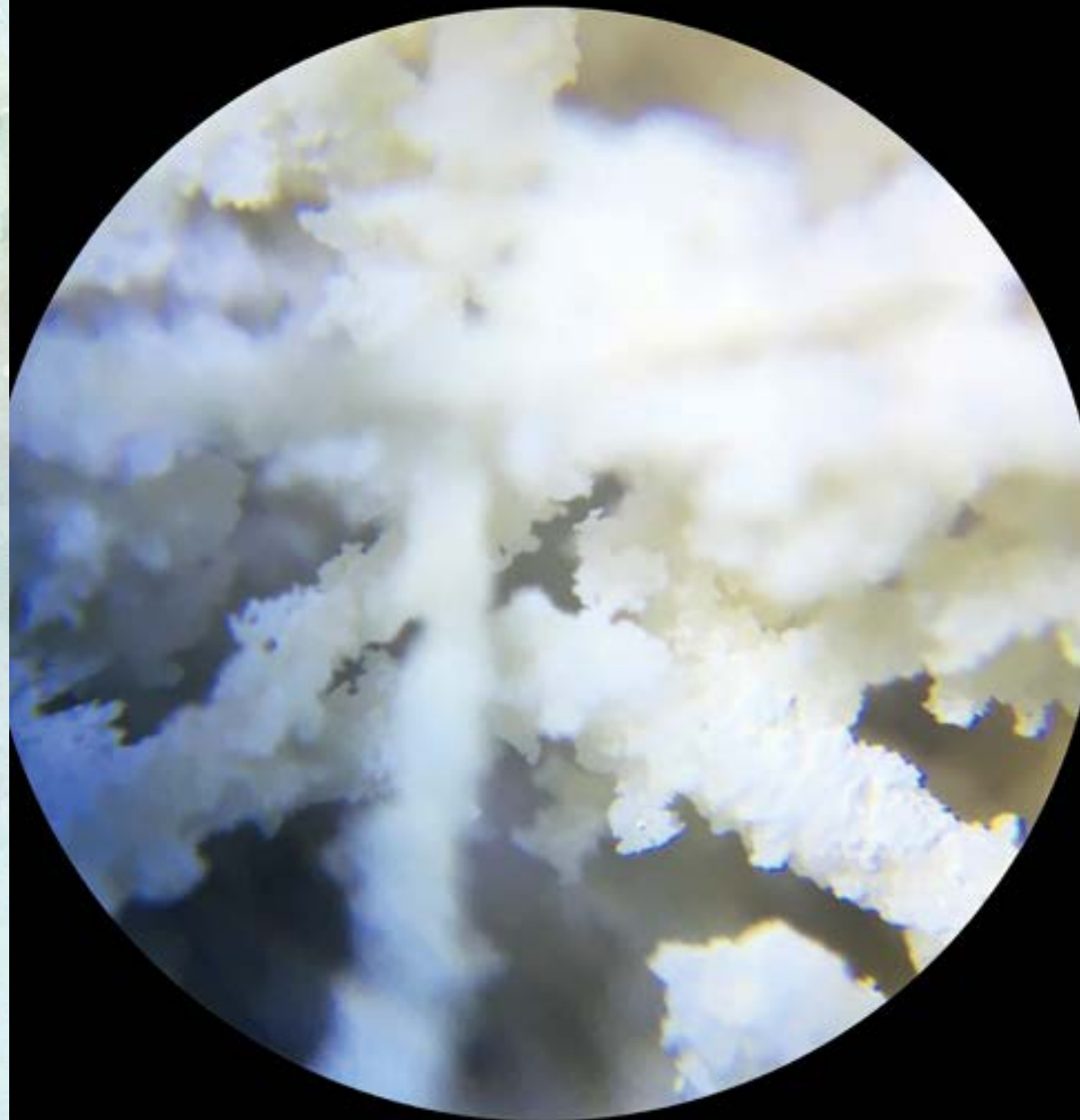
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# THE SCALE OF THE INTERIOR



## Introduction to textile thinking for adaptive and responsive interior design

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In architecture, textiles are traditionally used to create an interior lining for an inhabited space. As such, they occupy a middle ground between the body and the building in various ways: It is possible to think of textiles in interior spaces as both static and mobile surfaces that create temporary rooms that can be as close to the body as a garment or as far away as a carpet or a wall. Interior textiles are able to occupy the entire spectrum, from the scale of the body to that of the building, and serve as a mediating range between the two. Textiles have played a central role in shaping interiors since ancient times, often in a more static and ambient sense, as with soft furnishings, but recently a more proactive use is emerging, where room dividers or hybrid furniture serve as dynamic structural elements for interior space.

Fashion is naturally linked to the body; it is mobile and directly associated with the individual wearing it, therefore dealing with issues of social symbols, status, expression, and culture. Architecture, in turn, refers to textiles as a construction paradigm, but also as a formal reference for the shape of buildings. The works of architects such as Gottfried Semper and Frei Otto are early examples of textile properties and behaviour being used in architecture for both formal and structural reasons (Kuisisto, 2010).

Interior textiles, in contrast, do not fully belong to either the built environment or to the occupant of a space. They act as embellishment, affect the acoustic and aesthetic properties of a room, or serve as constructive elements within the building as spaces within spaces. In this sense, they can effect dramatic changes with regard to the scale and use of a space, while still relating to the actions and movements of individuals. Textiles, even in their traditional form, thus have the potential to 'reprogram' the meaning and function of a space and to open it up for new uses.

There is therefore huge potential in exploring this in-between scale from an interaction design perspective by looking at the engagement with space that interior textiles facilitate and enable. This is even more important now that the notion of 'interaction'

has been expanded beyond direct engagement with the material and into the digital realm: Smart textiles allow us to look at textile design with fresh eyes and to define new applications at the intersection of old and new technologies. The term 'smart textiles' refers to a broad range of material properties, among which electronic functionality is a subset (Hunde Dadi, 2010). They have introduced a shift from passive function and static patterns to active behaviour and dynamic expressions in the field of textiles (Worbin 2010).

The introduction of new types of expression necessitates changes in design aesthetics. Through the use of textile sensors and actuators, interactions with textiles become meaningful in a double sense: They become readable by microcontrollers, yet remain associated with the textile material. Digital technologies have introduced new dimensions of dynamic behaviour: Changes in appearance and thus changes in expression, in both reversible and irreversible forms. Examples of reversible change include thermochromic displays (Berzowska, 2004; Peiris, 2011) and shape-memory alloys (Berzowska & Coelho, 2005; Coelho & Pattie, 2009; Ohkubo, 2014); irreversible changes can be achieved by e.g. damaging the fabric structure through electronic actuation (Landin et al., 2008). These changes can be seen as a particularly accelerated form of dynamic expression, unlike the slow processes of decay and wear that textiles are also exposed to, but belong to the same general category.

By framing the phenomenon of digital textile materials as an extreme form of interaction, we can put it at the far end of a continuum of tangible interactions and expressions more generally, and not as something radically different from it.

In many ways, interactions with interior textile objects distinguish themselves from interactions with dress: They can be more deliberate and punctual, such as opening a curtain, leaning into the cushions of an easy chair, or spreading a tablecloth across a table surface. Or, put differently, interactions with interior textiles that are similar to those with clothing – e.g. tracking casual movements such as walking on a carpet – are the ones where textile interaction qualities are less important.

However, in the research field of smart environments, smart textiles have often been used, taking up the casual routine behaviour of the inhabitants and using it as digital input. Existing smart textile objects in the interior include carpets that track the inhabitant's location (Persson and Worbin, 2010; Sundholm et al., 2014) and curtains that light up in the dark (Müller, 2005). This is not to say that such projects do

not put smart textiles to good use: Many of them focus on the textile as a construction technique for smart objects, and explore the aesthetics that derive from it. But now that this groundwork has been done, there is the opportunity to address multiple textile properties at once, including interaction on different timescales.

A deeper exploration of the possibilities of interior textile interactions also requires us to question the basic categories of textiles as they exist today, and to come up with new and hybrid forms that move along the shifting boundaries between space and the human body. It is only then that we can provoke actions outside our established routines and interpretation patterns.

A way of achieving this is to look for mutual influences in the different layers of technology that are necessary to produce smart and digital textiles. To do so, we need to recall the fact that even the simplest textile surface is a complicated piece of technology, with its own embedded historical development and highly skilled craftsmanship. The familiarity of textiles in everyday life and the high degree of speed and automation by which they come into existence mean that textiles are often ignored or taken for granted. Therefore, when we combine textiles and digital technology, it is important to question and understand both in order to achieve the best synthesis.

In this way, smart textiles as an area of design and research has the potential to transform the craft and profession of textile design as a whole. This can be achieved by creating new types of materials that, through computational technology, make the material basis of the design process more abstract: dynamic patterns, reactive behaviours, etc. that, just like music, only 'exist' in performance, through use, in time. This will change the way we work, demanding new basic skills and a new approach to textile design practices.

One challenge for smart textiles that is of particular relevance in this context is to develop an approach in which textile design represents a lens or a paradigm to look at other technologies. Like other areas, textile design exhibits its own logic, which is grounded in the textile material's properties, the circumstances of its production, the contexts it is used in, and the social and cultural meanings it is associated with. To apply 'textile logic' to digital interface design means, for example, that we use the complexity and imprecision inherent in textile artefacts to design new interfaces, rather than trying to imitate the precision of interfaces and interaction devices constructed in metals and plastics. Here, contemporary design research work in smart

textiles shows a clear shift in perspective towards that of crafting technology. This influence is, in the best case, mutual (Buechley and Perner-Wilson, 2012).

Obviously, such an approach goes way beyond using textiles only as a host for standard electronics, or equipping everyday objects with digital sensors. The results might have more resemblance to the proliferation of industrial materials and production methods in design that was initiated by modernist designers at the beginning of the twentieth century: A reinterpretation of the purpose and application context of textiles, driven by the desire to challenge existing aesthetics and to explore the potential of new materials.

In this context, the notion of sustainability – one of the basic concepts of the project presented in this book – can be read in different ways. From an ecological viewpoint, textile production has a problematic history with respect to environmental issues, and the introduction of modern technology into the world of textiles may signal further problems along these lines. Seeing technological advances through textiles as a very general research programme can be used to develop viable solutions to this problem by changing the meaning of both textiles and technological artefacts. It is a way to open up new perspectives on subtle material complexities such as slowness and reflection, which allow the development of new ways of understanding the basic logic behind the textile expression, redefining areas of textile design as a design profession that addresses dynamic design variables and creating a narrative of alternative future ways of living.

These advances in the textile field have the potential to ensure the maintenance and development of traditions and skills in textile design, and in parallel enabling new uses and preserving the knowledge of craftsmanship of the industry that has shaped the landscapes and biographies of the world.

In this book we exhibit specific forms of textile-technology syntheses. The five examples of this programme presented here have addressed this field of tension in the topics of adaptive and responsive interiors, of bespoke textiles for interior performance, as well as designing for adaptive and responsive near-field interactions.

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TEXTILE STRUCTURES FOR  
ADAPTIVE AND  
RESPONSIVE INTERIORS  
(TEXTILE DESIGN)

Animating matter. Revealing kinetic capability in nylon monofilament through morphological transformation.

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New materials enable new ways of thinking and doing; they inspire and foster imagination. Materials ubiquitously attire our interior space, tacitly modulating the way we experience our surroundings. But what happens when materials become active, capable of responding to our presence or to stimuli in the environment by moving or changing their shape? How does this capability influence the way a space is experienced? Which new possibilities emerge for the design of interiors?

Motion can be “considered as a source of expressivity in itself”, not linked to the particulars of the formal features through which it is displayed (Bianchini et al., 2016). In the field of interaction design, movement patterns displayed through shape-changing textile-based surfaces have shown to elicit a range of different experiences in people observing and interacting with them; with these experiences being “richer” than those evoked by static objects (Vallgård et al., 2015). In robotics, simple movements performed by a non-anthropomorphic robot have been studied as a means of conveying robots’ social skills (Saez-Pons et al., 2014). Temporal patterns participate in the organisation of early subjective experience (Stern, 1985, p. 67), and the two remain intimately linked throughout life (Massumi, 2011, pp. 113-114). It is in the expressiveness of temporal patterns that motion’s eloquence relies.

Given that textiles are inherently soft and flexible materials, they can be deformed and made to conform to different shapes through folding, draping, pleating, stretching, etc. This capacity to reversibly change their shape makes textiles ideal vessels for movement. However, intrinsic, responsive shape-changing is an under-explored quality in textile materials.

Advances in the field of material science are increasingly providing unique opportunities for designers to explore and experiment with novel material properties. Developments in actuator fibres and artificial muscles become of particular interest to textile design when considering a material’s capacity to perform reversible, responsive movement. Targeted primarily for use in robotic systems and prosthetics, actua-

tor fibres and artificial muscles comprise a vast array of fibre-based materials and technologies that have the capacity to reversibly change their shape in response to a wide range of stimuli, such as temperature, moisture, light, and chemicals. Textile materials exhibiting responsive kinetic capabilities open up the design space by supplementing the traditional compositional elements with which designers engage, such as pattern, form, colour, and texture, with a new layer of dynamic expression.

Interior spaces have historically been equipped with a wide range of textile surfaces and artefacts, fulfilling both functional and decorative requirements. In an analogy to the way variations in sound and light intensities are extensively used to tune atmospheres and increase comfort in interior spaces, patterns of velocity, starts and stops displayed through responsive, kinetic textile surfaces and artefacts, carry the potential to dynamically contribute to the creation of atmospheric tones in interior spaces.

Arising from an appreciation of the expressive potential of motion, this work aims to expand the range of material behaviours available to the field of interior design by exploring how textiles can be endowed with inherent capability to perform responsive, organic movements. In so doing, new opportunities for the creation of experiences in interior spaces are suggested. Building on developments in the field of material science that enable the formation of fibre-like, heat-responsive actuators from polymeric monofilament by twisting and coiling (Haines et al., 2014), coiled nylon actuators are explored as kinetic materials for textile design.

Coiled actuators were introduced in 2014 as artificial muscles for use in robotic systems and textile actuators. They can be formed by twisting and coiling polymeric mono- and multi-filaments, such as those developed for high-strength applications, for example fishing line and sewing thread. Two basic types of coil have been described: twist-induced and mandrel coils. While twist-induced coils respond to heat by contracting from a stretched state, the behaviour of mandrel coils can be tuned to either perform a contraction or an expansion, depending on the way the coil is formed (Ibid.).

An initial hands-on engagement with basic coiled structures resulted in an unexpected physical outcome, arising from a mistake made while testing the behaviour of a mandrel coil. The nature of this event foregrounded the active participation of material properties, capacities, and tendencies (DeLanda, 2004) in the outcomes of

my practice – a tacit understanding that, as a textile designer, I had acquired through extensive involvement with materials, processes, and tools.

The idea of matter actively participating in the process of generation of form and structure is conveyed in the notion of morphogenesis. In opposition, hylomorphism denotes the idea of matter being a passive and inert receptacle of form imposed from the outside (Deleuze & Guattari, 1987, pp.475-476; DeLanda, 2004; Ingold, 2013, pp. 20-21). DeLanda explains that attending to matter's complex behaviour and intrinsic self-organising capacities may allow us to "think in the origin of form and structure not as something imposed from the outside on an inert matter [...] but as something that may come from within the materials, a form that we tease out of those materials as we allow them to have their say in the structures we create" (DeLanda, 2004, p. 21). Ingold suggests that making is a "morphogenetic process" emerging from the "confluence of forces and materials", and describes making as a "process of growth" where the practitioner "joins forces" with the materials in the generation of form (Ingold, 2013, pp. 21-22).

Acknowledging the active role of the material in the process of making, subsequent stages of exploration followed a bottom-up, open-ended approach that favoured the manifestation of the material's expressive attributes. Engaging in direct, hands-on manipulation of basic coils, which hinged on heightened attention to material cues, the exploration unfolded as an intuitive, improvisational dialogue with the material, "try[ing] things out and see[ing] what happens" (Ingold, 2013, p.7). Following such a morphogenetic approach to making, a strategy of combining transformation techniques emerged through the exploration, revealing unforeseen kinetic monofilament morphologies. While basic coiled structures are generally used to perform linear contraction or expansion, the exploration showed ways in which the revealed kinetic morphologies could display multidimensional, thermally-induced behaviours, depending on their arrangement in the activation set-up.

Subsequent exploration of the formation of kinetic morphologies in a structured and targeted way enabled to formalise processes of transformation of nylon monofilament into kinetic morphologies. Elaborated into recipes, these formation processes become available for further exploration. Structured and targeted exploration of the material additionally exposed the nuances in structure and behaviour that the formation process imposed on the resulting kinetic morphologies. While variation is not traditionally a desirable attribute in the structure and behaviour of the materials

we work with, the nuances resulting in the morphologies due to the particulars of the working setup enhanced the organic character of their aesthetic attributes and kinetic performance. Encompassing uncertainty within design strategies by learning how to work with inconstant material properties may widen the space for expressive opportunities to emerge.

Basic coiled actuators and kinetic morphologies can be assembled as modules into configurations inspired by the characteristic interlacing of linear elements in constructed textiles, enabling the formation of kinetic surfaces and three-dimensional structures. By supporting the reproduction of kinetic morphologies, the aforementioned recipes additionally enable further exploration of assembly strategies.

The transformation of nylon monofilament into heat-responsive morphologies with kinetic behaviour and enhanced aesthetic qualities opens up the design space of textiles; it offers new opportunities for designers and artists to explore kinetic expressions for textile-inspired assemblies, with the potential to provide novel experiences in interior spaces.

The future development of this work includes the integration of conductive elements in the kinetic morphologies in order to enable their activation and that of kinetic assemblies through resistive heating. The activation of basic coiled structures through heat provided by an electric current passing through a conductive material has already been demonstrated (see e.g. Haines et al., 2014; 2016; Yip & Niemeyer, 2015; Mirvakili et al., 2014), paving the way for the formation of kinetic morphologies in combination with conductive yarns or commercially available silver-coated monofilaments. Activating kinetic morphologies and assemblies through resistive heating increases the controllability of the structures' behaviours, allowing specific patterns to be designed by modulating temporal elements such as speed, starts and stops. Additionally, resistive heating could enable the selective activation of individual component modules of kinetic assemblies, providing the potential for designing a range of different behaviours within a single assembly. Lastly, activation through resistive heating facilitates the integration of kinetic morphologies and assemblies, together with sensors and processing units as part of responsive and adaptive material systems. Combining kinetic morphologies with thermochromic liquid crystals or leuco dyes is also foreseen as a means of expanding the scope of the dynamic expression of kinetic morphologies and assemblies.

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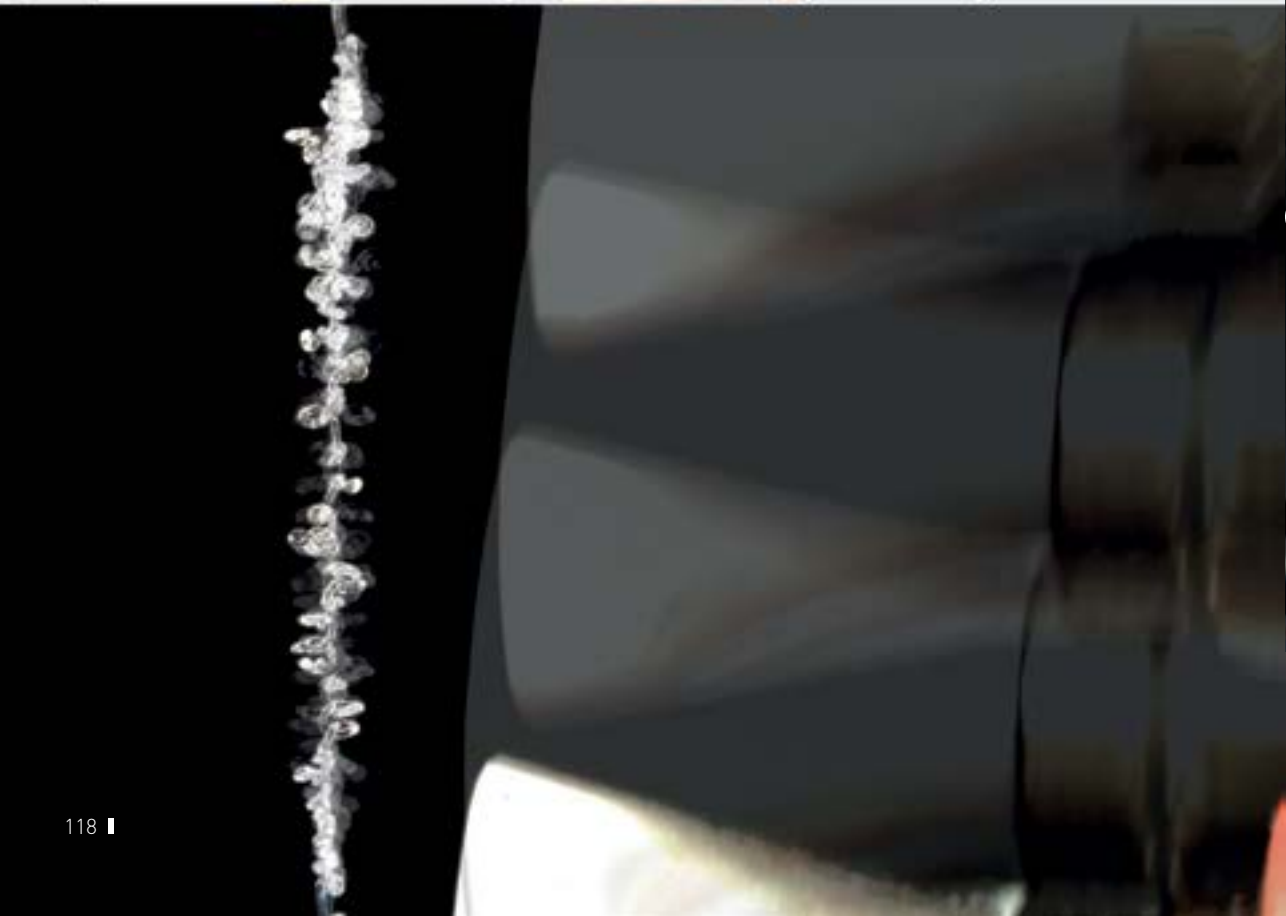
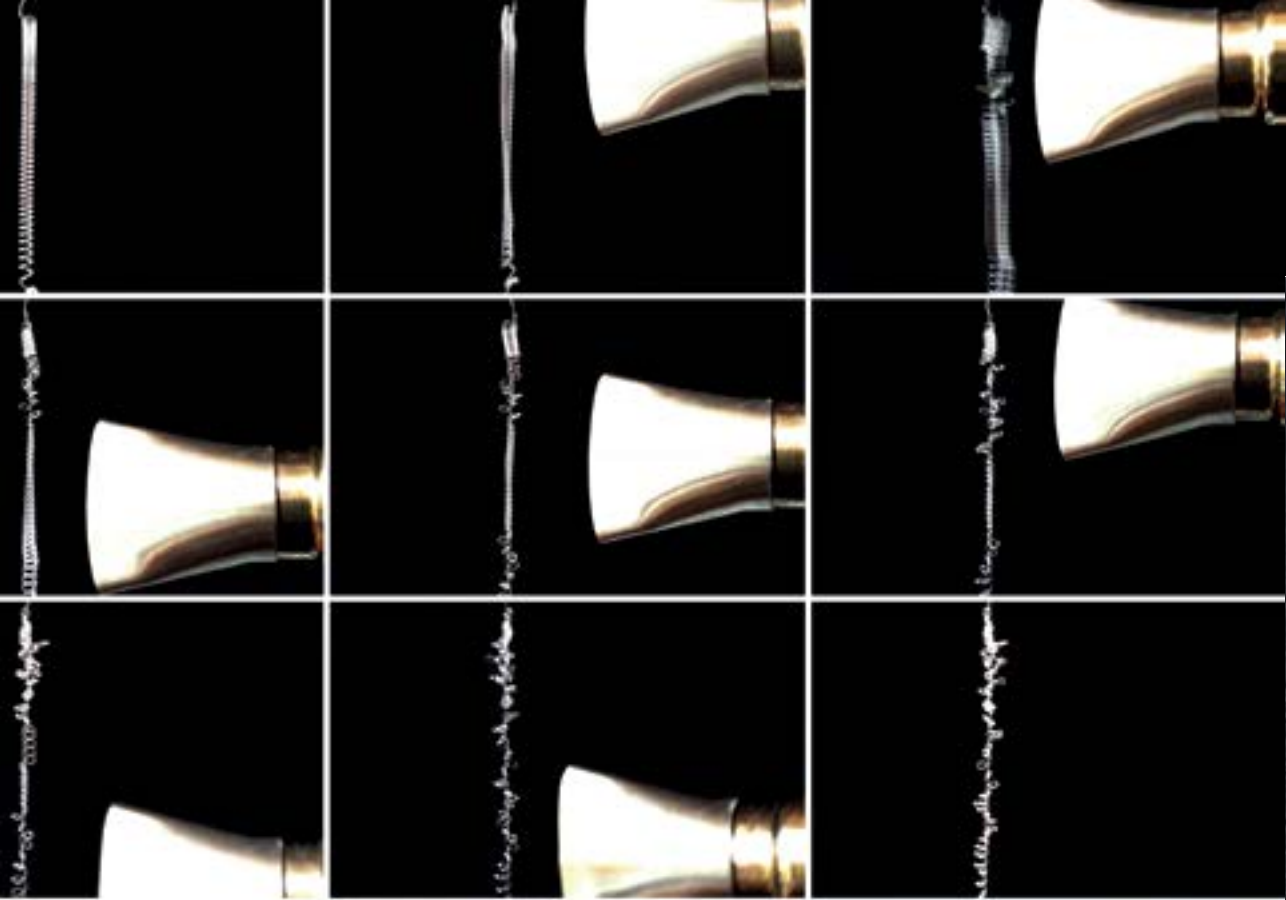
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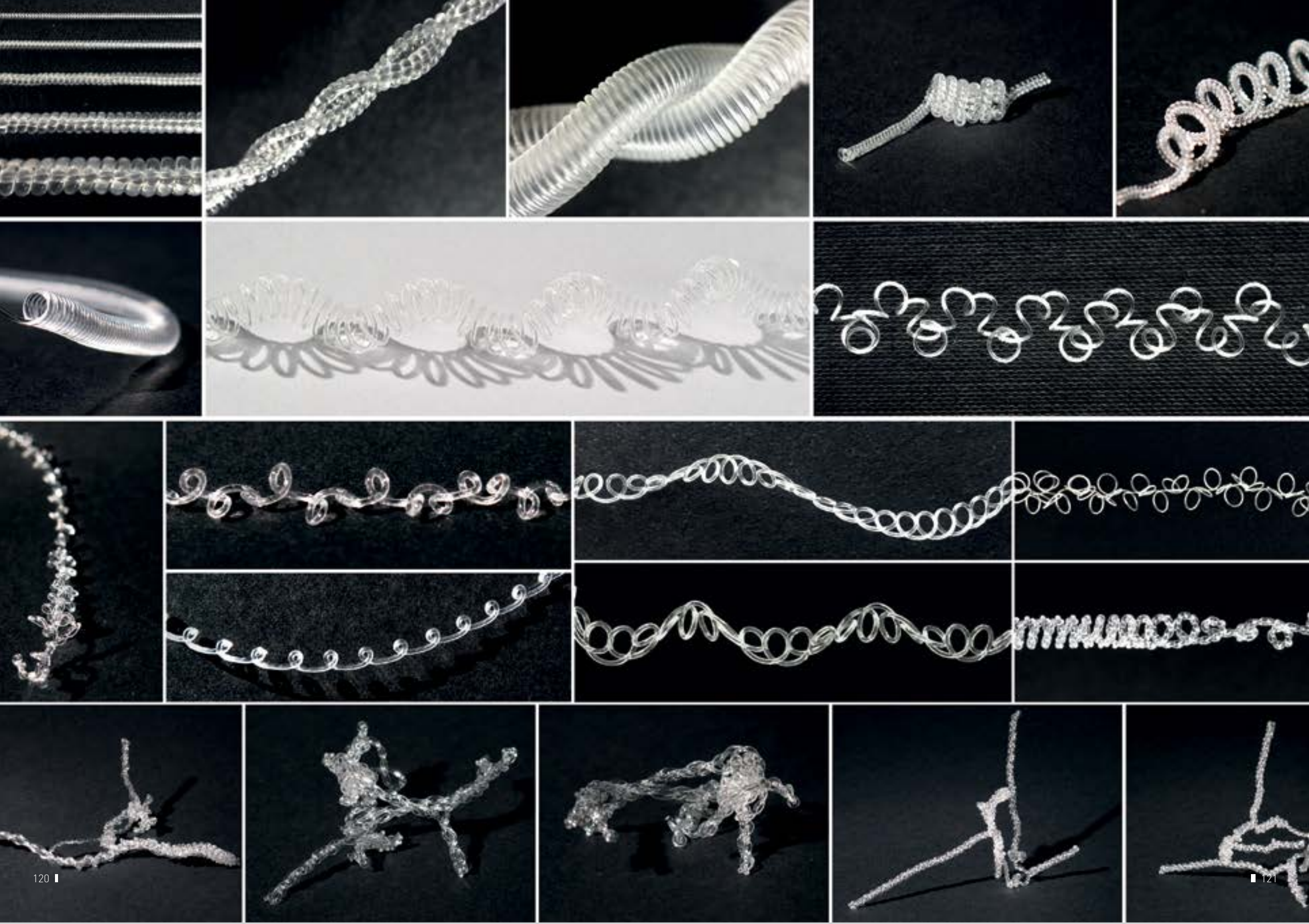
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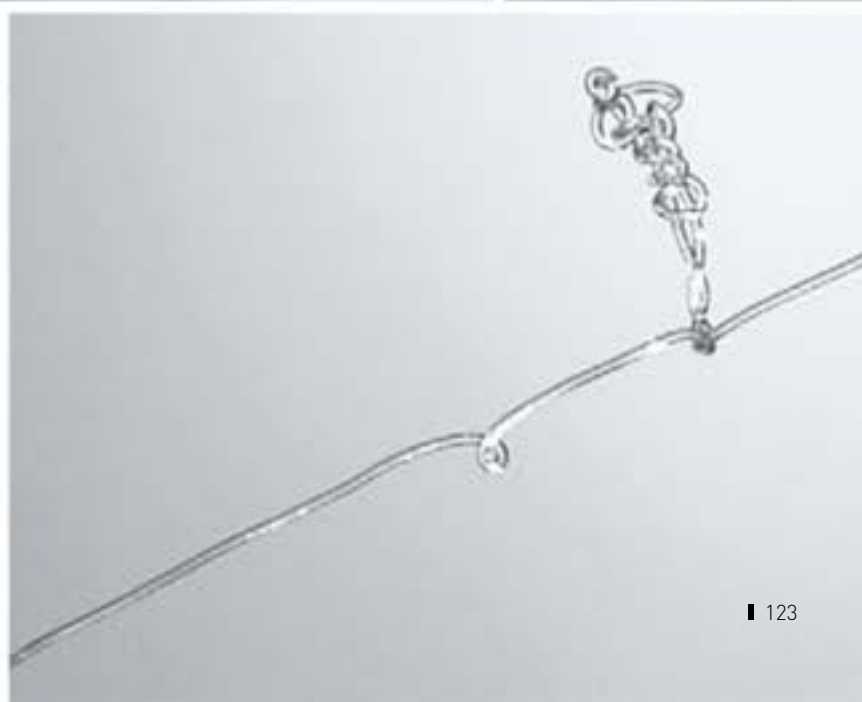
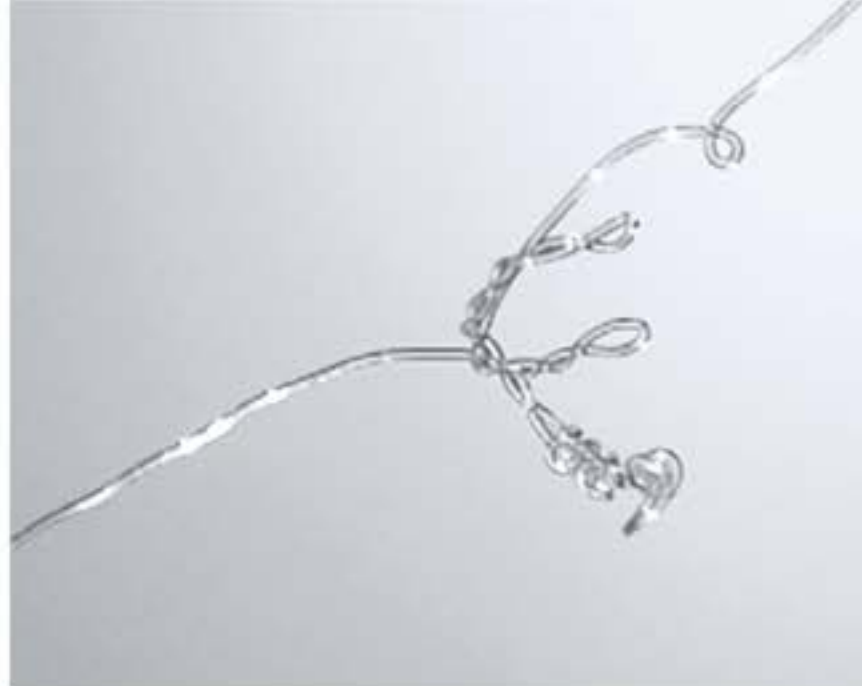
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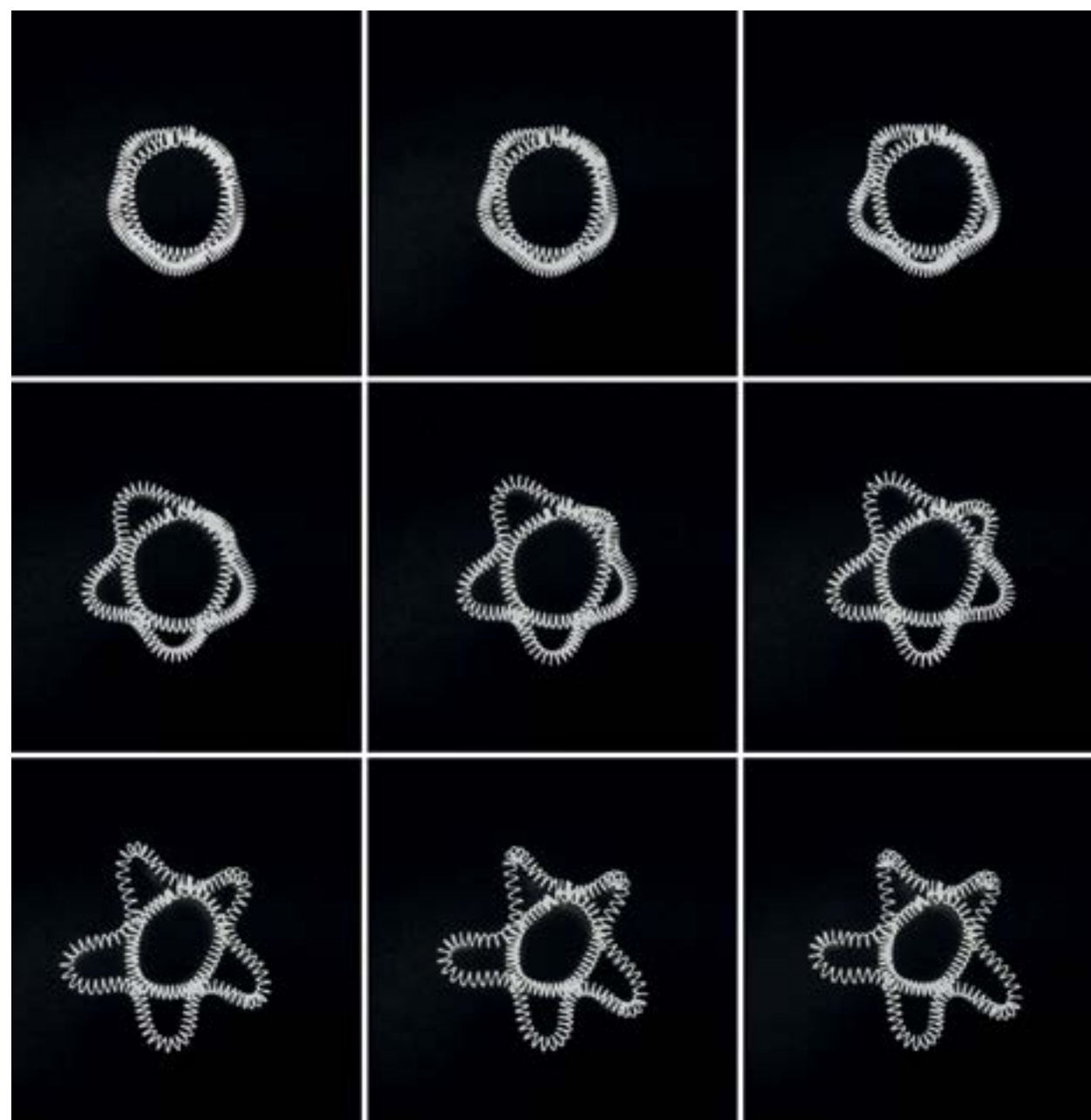
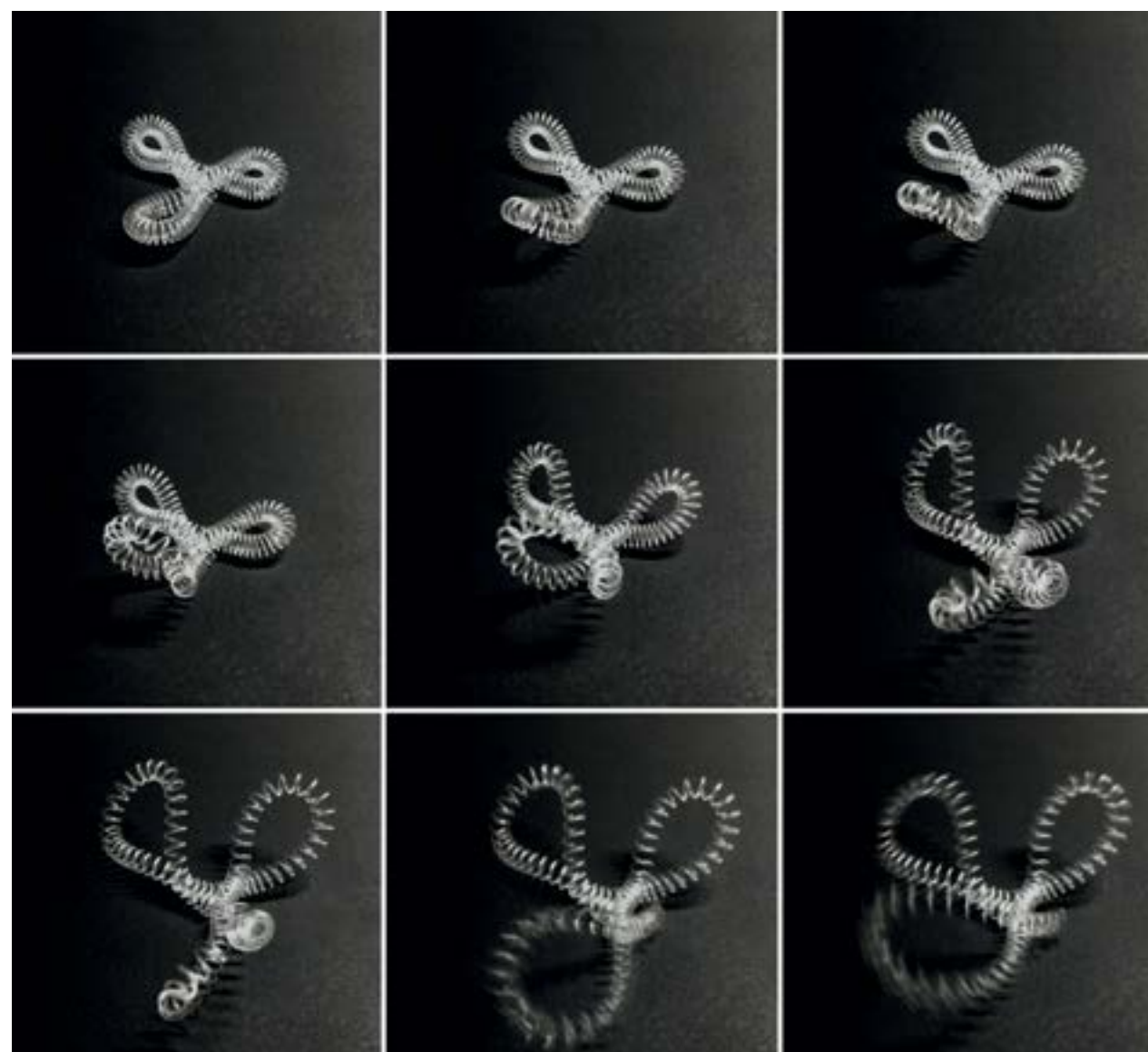






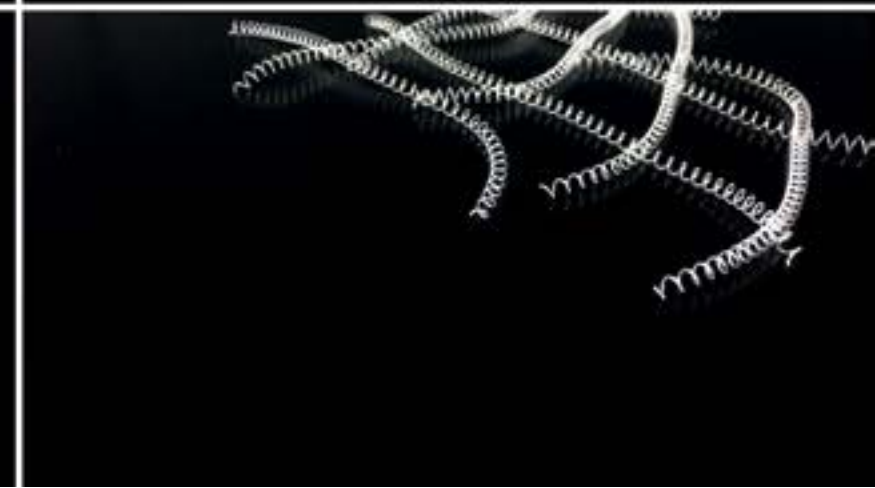
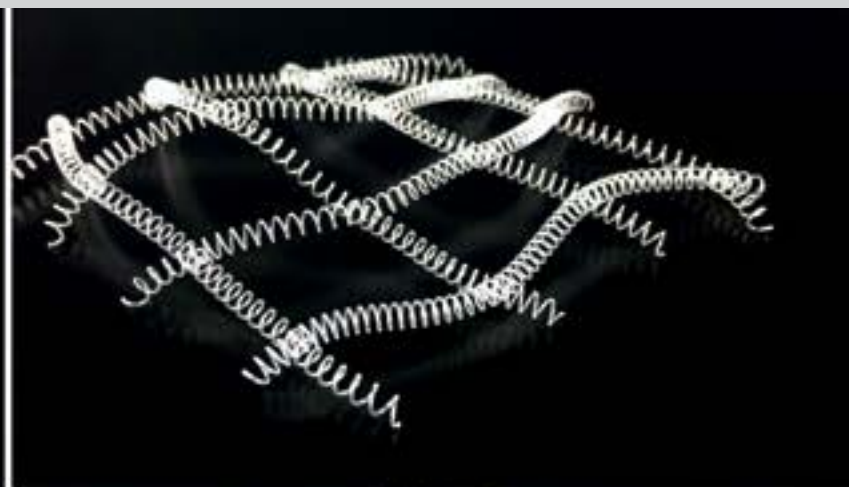




















## On Textile Farming

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Textiles are fundamental materials for interiors. Similar to the role of clothing on the body, textile surfaces dress interiors as elements of décor, comfort, and function. Through patterns and textures, textile surfaces mediate our daily visual and tactile experiences with objects, spaces, and bodily interactions in space. The ways we experience indoor spaces, e.g. by sitting on a sofa or walking on a carpet, are determined by the inherent attributes of textiles, e.g. patterns, colours, textures, and their sensory perceptibility.

In the past decade we have experienced a change in textile practice and witnessed the development of smart textiles and responsive environments, driven by a technological paradigm. Research prototypes and design methods have been developed to create dynamic materials and responsive textiles using digital technology. Moreover, developments in the design of responsive materials with transformable characteristics, e.g. changes in colour, texture, or shape, have motivated textile designers in their search for nuanced ways of designing surfaces and spaces by taking advantage of new, digital materialities. In expanding upon the static character of conventional textiles, the responsive expressions of smart textiles for interiors are seen as a new foundation for designing complex aesthetic experiences which shape daily activities and enable novel ways of participating in and co-designing environments. But is responsiveness in design always bound to digital technology?

Over course of two decades, the design of responsive textiles and interiors has referred mainly to technological paradigms. However, recent biological breakthroughs, such as the discovery of interplant communication through mycorrhizal networks (Simard et al., 2012), developments in genetically modified organisms (GMOs; Phillips, 2008), and works of art in the fields of bio-art and bio-design, have opened up for alternative perspectives. Here, the advantages of natural systems and bio-materiality are acknowledged and used to design assemblies ranging from dynamic materials to responsive architectural structures. Likewise, the characteristics together with the natural behaviours of materials add a new perspective when designing responsiveness. Speculative examples in the field of textile design and product design explore the potential of natural systems, e.g. insects, fungi, or bacteria, as

new methods for design and manufacturing processes that are related to biological processes (Collet and Foissac, 2015; Collet, 2012; Pinto et al., 2013). Hence, rather than programmed, computational behaviour, bio-responsiveness as a design criterion is dependent on the life cycles of natural materials and human maintenance. Here, responsiveness presents a new perspective on biological materials, positing them as both a means of design exploration and a new area of human interaction.

We examine seeds as design materials for textiles and interiors, driven by the question of how growing plants and living with textiles can become one. Seeds, as responsive natural systems, are able to sense and interact with their environments and respond to changes in these. Thus, they can be understood as smart materials. One can print a thermochromic floral pattern on a curtain and program it to change the surface design, or grow seeds on textiles to generate arrangements of edible flowers. In contrast to other smart materials, seeds not only change the expression of a surface in terms of shape and colour; they embody the potential to develop into a thirsty grass, a bulky beet, a delicate flower, or a huge tree. Thus, they can be used to create responsive textiles and spaces that challenge everyday aesthetics.

Textiles as support for seeds can be used as part of the indoor gardening to organise and facilitate the growth of plants. Due to their adaptability, textiles can support seeds through indoor gardening, organising and facilitating the growth of plants. The variation of textile attributes in the textile surface makes them a suitable material for supporting growth; textiles can be flexible or stiff, straight or folded, permeable or impermeable, horizontal or vertical, tight or loose. These qualities can be implemented, even in the same piece, using materials that e.g. absorb or repel moisture, keep a shape or adapt to another form, are fluffy or flat. The integration of seeds as materials for textiles is a challenge for structural design, i.e. meeting the needs of plants. These challenges require special settings for textile structural techniques, such as weaving, as the structure should contain or connect to supply systems to provide the plants with nutrition and water, in addition to the substrate that the textile itself constitutes already. The change in expression of the seeds when implemented in these textiles add additional perspectives to the elements of design of textile surfaces: structures, textures, patterns, and colours. The textile design process lays the foundation for aesthetic combinations, oppositions and contrasts.

As a result, there is no final expression; instead, there are dynamic changes through reactions and adaptations over time. The expressions are proposed, rather than being

determined solely by the designer – they are a product of the interplay between various actors, including the designer, the user, the biologically active textile-plant hybrid material, and the environment. The designer designs with a design intention in mind, e.g. a membrane as a piece of spatial design which serves as a selective barrier that allows the purification of water through a textile-plant hybrid, a circular flow, and in exchange between people and space. The user arranges and cares for the hybrid material according to instructions, existing knowledge, or intuition, and therefore influences the environmental conditions. One could say that the user becomes the gardener of an ecosystem, e.g. a building. The biological agent (a seed, plant, or bug) carries out its inherent blueprint in relation to this environment, which is in turn influenced by the interplay of all of the involved biological agents and textile components.

By expanding the function of vegetation beyond aesthetic values, plants can also grow to be a source of food by generating alternative scenarios of urban living. This biological perspective requires changes in not only how we define textiles but rethinking the interior as an ecosystem made of living (biotic, e.g. people, plants) and non-living (abiotic, e.g. soil, water, furniture) components, in which the components interact with one another and the environment through nutrient cycles and energy flows (Odum, 1971) in a specific, limited space – the interior (home) in this case. Sprouts can grow on textiles in order to support residents with décor and comfort, and they can anchor themselves and the textile by rooting to become a more permanent piece of the interior. Additionally, seeds can be seen as generators of food; a carpet-high pile of chives, for example, can also be lifted to the height of a table or placed on the ceiling. With research developments in interplant communication, roots could not only be used for stabilising or connecting purposes or cleaning water or removing it, but they can transfer information and exchange nutrients with the help of mycorrhizal networks. Seeds as materials for textile design generate different speculative futures in terms of aesthetics and possible uses, but they also generate concrete questions regarding the design of textile structures that are able to host seeds, and the forms of care necessary to support plant.

The durability of textiles generally determines their useful lifespan. Embedding seeds in textiles opens a new perspective on textile lifespans by adding the life cycle of each bio-material. The textile will then be a support or template, where parts flourish or biodegrade over time. Therefore, they will be used in the future to significantly transform an interior in the short or long term, or the textiles will be moved outside

to continue their development in a different environment. Consequently, seeds as materials for interior textiles will not only expand their areas of application towards indoor gardening, but also towards more structural, architectural fields as the development of plants is continuous and irreversible, covering minutes to decades.

Hybrid textiles that influence the presence and purpose of intertwining textiles and plants in interior spaces, as well as beyond, will open for engaging experiences with residents: from activities, e.g. food production, to spatial interactions. Sprouts will be harvested and eaten, flowers from floral curtains can be picked, a carpet can be moved regularly to keep the right pile height and to avoid it sticking to the floor. Shapes covered with grass will be able to accommodate our bodies. Tents will be planted and turn into permanent buildings that expand over time and change with the seasons. Accordingly, responsive textile plant interiors can be a new resource for architectural design, also in dense urban areas. This can be seen as an alternative to conventional urban gardening, and represents a possible step towards the development of resilient cities with sustainable local food production (Hawken, 2008). This visionary model of interiors will provide a new form of contact with surfaces and nature, especially in dense urban areas. Activities of food production, e.g. cultivating, maintaining, and harvesting plants, and textile interactions, e.g. walking over a carpet and closing a curtain, will become one, bringing together gardening and living, and this will be facilitated, mediated, and guided by the qualities of textiles.

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DESIGNING BESPOKE TEXTILES FOR  
INTERIOR PERFORMANCE  
(TEXTILE AND FASHION DESIGN)

Fashion design - towards a new vocabulary in  
dress

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Clothing and buildings provide essential functions for the body, as well as give full expression to humans' way of life. Architectural theory has a long tradition, and has accumulated a wealth of different theoretical discourses concerned with all aspects of architecture, from design and construction to meaning, politics, deconstruction, and sustainability (Alexander et al., 1977; Pallasmaa, 2005; Krier, 2009). In contrast, the theory of clothing is younger, or at least the collected theoretical notions of clothing over the years are much more scarce. However, the field is still gaining momentum, and theories on and about dress and the dressed body have in recent decades developed rather intensively, and so has the variety of perspectives from which clothing and fashion are being analysed (Barthes, 1983; Entwistle, 2000, Barnard, 2002; Aspers & Godart, 2013). These theories include perspectives on clothing and fashion borrowed from art, design, technology, the social sciences, and the humanities, where issues such as identity, gender, meaning making, linguistics, politics, as well as the art and design of giving form to embodied expressions are explored.

As an often-overlooked yet strong normative force, the foundation of fashion design as both practice and theory lies very much in a series of forms that define garments. As a series of units, it not only provides inspiration for design development, but an arguably more or less monopolised direction for the understanding of clothing and development of fashion design.

These units, in the shape of different types and versions of garments, are often presented in different kinds of books on the categories of fashion and clothes' evolution through history. These categories could include day wear, evening dress, sports and leisure wear, accessories, underwear, and wedding garments, and be accompanied by descriptions of colours, cuts, necklines, lapels, sleeves, pockets, fastenings, buttons, and belts. In addition, a historic development of the categorical expressions of dress – the evolution of fashion and garment shapes – is commonplace, and for example expressed like this: “from the boyish silhouette of the 1920s and the sophisticated outlines of the 1930s through the plain utilitarian 1940s and the new femininity of the 1950s, to the radical styles of the 1960s, the vintage and ethnic trends of the

1970s, and the structured 'power dressing' of the 1980s" (Peacock, 2006: 7).

Thus, in order to open up a wider range of possibilities in fashion design, a programmatic shift in fashion design and embodied expressions through dress is needed. In relation to architecture and interior design, and with the growing interest in interiority, the double nature of the interior and exterior aspects of shared physical spaces – the in-between – as a process rather than a unit could provide such an opportunity.

Examining the potential for the expression of the body through open spatial explorations that disregard the conventional purpose of dress (the fashioning of the body) and interior design could lead to a new understanding of the implications of fashion and interiority: that they are neither clothing nor building, but both fashion and architecture. Such vocabularies would also permit new perspectives on the dressed body, while enabling new ways of formulating it.

A central challenge for vocabularies of this kind is to formulate a cohesive theory of form within fashion design and fashion theory research that builds on the interiority of garments as space. To do this, the work explores and demonstrates the fundamental relationship between fabric, form, and the body in order to develop a system for understanding these relationships and the designing of the form, and hence expression, of the body. From these explorations of body/dress relations, structural examinations create the foundation for a theoretical understanding of the form of the dressed body, and so a new theory of form is developed.

Drawing on a range of research dealing with form (designing and systematisation) in related fields such as architecture, dance, and art, as well as comparing dress structurally to language, the investigations operate to understand the dressed body as a 'total form' and comprehend the physicality of the dressed body as relational. This is undertaken through material investigations and installations, a new vocabulary of form, and comparative analysis (of forms of the body).

Methodologically, the work operates in between the scale of the body and the scale of the interior and revolves around two main focuses: 1) the nature of the human form and 2) the function of clothing to communicate this nature. The work was carried out using a hands-on, practice-based method of open-ended exploration to gather examples of relational forms (the result of a body in relation to the material) that could be used for analysis. The array of examples enabled the development of methods to

analyse the relationships as a foundation of form, e.g. the expression.

Starting with simple relationships, such as the standing and seated body covered with cloth, this work evolved into more complex forms of relations where different frames, prints, and transparency of material were used. What emerged is an array of form examples that show the potential for human expression, ranging from very small and rigid to solid and organic structures.

The outcome is a range of visual examples of relationally based body forms. The structures are the result of exploring different definitions of form through relationships between body and material, meeting points, in-between spaces, and gravity and tension. Hovering at the intersection of the body, dress, and architecture, the forms play a vital role in our understanding of the expression of the (dressed) body, and serve as a base for the development of an analysis tool – a new means of interpreting meaning – to be applied to form in fashion as a tool for analysis and for designing.

These results suggest a new vocabulary of expression and forms in fashion design through the development of a broad range of examples of expression and forms that are presented as the relationships between properties through meetings and intersections of intermediate space and 'total form'. This includes a vocabulary for the description, transcription, and analysis of form for fashion design and interior design through a deepened material understanding within the field of fashion design. However, the expressions are not constantly presentative; the expression of the interior is rather an event during which the body is in constant development through dress. As more of a bank of emerging ideas than a closed and set system of categories, the space that is established in the series of forms could therefore better be understood as a proposition of aesthetic interactions through the body-dress-space relationship, as a non-established a-priori entity that is created by a process that develops through the structure of matter (Leibniz, 2005). Rather than being representative and relying on detail, fashion expression is here a lived space at the border between private and public space; a construction that is as much liveable space as it is a concept of dress. From one perspective, the forms are the construction of an extreme, subjective experience, a kind of intimate poetic space such as that described by the intense space of bodily presence (Böhme, 2003). On the other hand, the forms are also instrumental object-based representations of a person established in space. In a way, the work negotiates a converging subject and a diverging object through the concrete internal experience it produces, and the abstract external rationality it presents.

Together, the examples imply a potential for a new and broader understanding of interiority through the dressed body as 'total form', along with further insights into the materiality of body, which has implications for the development of fashion theory and architectural theory. These new understandings examine established arguments for a philosophical understanding of form as an interior relationship between the expression of the dressed body and the creation of the human expression as an interior event that is realised through the space of the dress. The result has the potential to broaden existing design methods in architecture, interior design, and fashion design, professionally and in practice. Moreover, it may inspire other fields to investigate discourses beyond those of a strictly visual nature. In accepting the interactive interior qualities of body-dress-space relationships over garment categories or architectural structures as a-priori entities, new vocabularies that can present dynamic alternatives to fundamental theory and methodologies, full of diverse potential.

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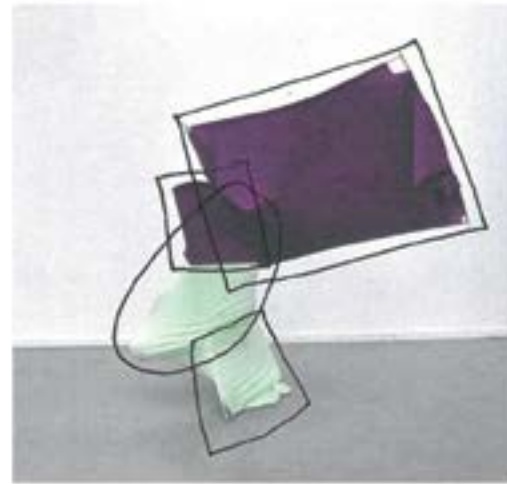


















## On interior atmospheric staging

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*Let us imagine 'The Atmospheric Staging Studio', where designers stage and film 'interior scenes' with material props. Spatial atmosphere is their brief. Materiality is their brief. The 'atmospheric stagers' act as location scouts in the film industry. They look for inspiring environments to play with both inside and outside spaces. The 'staging sessions' take place during different seasons, at different times of day. Surfaces, lights, camera, and bodies generate atmospheric effects. The performers use textile props of abstract shapes, diverse sizes, and different properties to stage interior situations. These 'atmospheric props' can be carried, worn, or moved around. They modify existing spaces through dressed furniture, bodies, surroundings, and additional staging equipment in order to, for instance, change the lighting conditions. The 'atmospheric stagers' build the 'atmospheric settings' of diverse constellations and nature, in response to what the space and the material properties can offer. These settings enact interior situations, such as light-surface sequences, light-colour-surface sequences, and light-colour-smell sequences. The 'atmospheric stagings' can be very slow and contemplative. They can also be active and engaging. Sometimes the 'atmospheric dwellers' use pre-written instructions, at times they improvise. The setting can be activated by performers, or be left to be performed independently. Thereby, the interior nearly becomes a landscape, a perpetual stage for the scenes to unfold unexpected and welcoming sequences of lights, shadows, colours, smells, and sounds.*

Aspects of materiality and atmosphere usually come together. Interior surfaces with different qualities sculpt light, direct air currents, activate colours, and animate shadows in different ways. These dynamic, accidental occurrences and sometimes even subtle micro-events are crucial for our aesthetic spatial experiences: The astonishment, the randomness, the traces of life that arise from material realities and our interactions with them. This is apparent within natural, historical, and vernacular settings (Pallasmaa, 2014). With regard to carefully designed environments, the ways interior surfaces can be combined are manifold, and scenographic practices show that surfaces catalyse dynamic effects and create relationships between the atmospheric elements within a setting. Atmospheric effects result from 'staged materiality' (Böhme, 2013). In interior modelling, such gestures (Tawa, 2010) rarely take place due to the fact that design processes are usually based on fixed interior

situations rather than changing sequences. However, emerging architectural theories claim that the performative qualities of spatial modelling are closer to scenographic practices (Brejzek and Wallen, 2017) and cinematic approaches (Penz, 2017). They present opportunities for design processes to be liberated from essentially pragmatic and mimetic ways of modelling by emphasising their explorative, transformative, and performative potential. From the perspective of materiality, textiles offer great adaptability. They are more adaptive than static architectonic forms. They are smooth, lightweight, easy to form, and they can change surface properties and therefore invite a wider range of design gestures.

'The Atmospheric Staging Studio' approaches interior modelling in a paradoxical way. It explores the act of modelling as atmospheric staging with material props. The studio sets material settings in full-size environments. Therefore, instead of engaging with physical-scale models, stagers perform interior scenes through material surface constellations – 'atmospheric settings'. Both immediate interactions and their recordings are taken into account as 'atmospheric modelling', or the 'atmospheric staging' process. The camera also performs and transforms interior scenes through framing and setting parameters. The surface constellations are in continuous rearrangement through enactments with props, aiming to catalyse 'atmospheric wonders'. The studio plays with the most basic atmospheric variables: colour, light, time, movement, and – less commonly – smell. Material props are usually textile surfaces of different properties that relate to these aspects: the reflection and emitting of light, the embedding of smell. The modelling process is initiated by the material realities that the props can offer. Some of them are designed by other researchers and artists, some remain just as found. Sometimes the studio explores ad-hoc, random interactions. It may even be the case that the setting acts 'alone', as when light shifts and air movements activate a set-up. At other times, brief instructions are given to the performers beforehand.

Experiential modelling forms such as 'performative installations', 'atmospheric devices', 'chromatic probes', and 'atmospheric rooms' are practical examples of artistic explorations that make the process of atmospheric modelling palpable, and help question the conventional forms of expression. "Perceptual events" (Massumi, 1998) and 'atmospheric interior wonders' cannot be explored and expressed through commonplace interior design media such as drawings and scale models. The role of the representational medium is crucial in modelling, as every small choice of representational technique defines the produced atmospheric effects (Wigley, 1998). Hence, the 'atmospheric settings' explored by the studio relate to the art forms of installations

and happenings. A series of 'staging sessions' are set through a hybrid workshop-performance format, involving the textile, photographic, cinematic, and performance arts. The 'scenes of interior performance' are produced as a consequence of the 'staging sessions'. Interior representation tools shape and condition the designer's spatial understanding and produced spaces (Pallasmaa, 2010). Recent publications on the relationship between modelling and staging demonstrate that representational techniques that relate to the stage and staging practices have a great deal to offer for the well-established 'architectural representations' field (Brejzek & Wallen, 2017).

'The Atmospheric Staging Studio' focuses on the act of modelling from performative, speculative, and atmospheric perspectives. It takes its inspiration in the historical link between spatial designing and staging. Staging, when seen as a scenographic and cinematographic technique of representation, is a highly creative research tool and strategy; simply start thinking in terms of 'scenes', 'frames', 'props', 'set-up', and 'sequences', and a new world for the designing process opens up. Modelling, when approached as 'atmospheric staging', disturbs the usual modelling practice and its forms of expression. 'The Atmospheric Staging Studio' adopts the logic of modelling with bespoke material accessories, i.e. 'wearables', 'movables', and 'screens'. The context of modelling is set through the dressed furniture, bodies, and environment, and creates dynamic sequences; 'the scenes of interior performance'. In this way, the dominant thinking through models in architectural representations is being shifted through 'textile thinking'.

The discussion which then arises relates to the atmospheric aspect of settings and staged scenes. How does the setting perform: what models what and who models what? Ultimately, what do the scenes trigger in terms of atmospheric imagination? The activities and rhythms that emerge from the staging sessions can be defined as characteristics of staging, as with the slow movements with light reflectors or active engagement with lighting equipment. These interactions trigger expressive material qualities, e.g. changing lighting conditions reveal different existing and potential material behaviours and performances. Thus, bespoke surfaces can be created according to the unique nature of the setting, and vice versa. Hence, this approach opens a path for adaptable interior design: textile props are open-ended forms that work as catalysts for effects (Massumi, 1998).

Filmed interactions then become a source for speculation and discussion regarding these effects; what if, for instance inhabitants' garments also took part in the

atmospheric setting? What if interior surfaces were designed and combined in such a way as to affect the lighting and/or olfactory conditions of a space? Moreover, the interactions – framed as interior scenes – open up for further investigations. 'The Atmospheric Staging Studio' is particularly interested in the potentials of cinematic images with regard to not only modelling, and transforming but recording interior occurrences. If the videographic practice constitutes a form of spatial practice and images produced are capable of bringing a new awareness of architectural atmospheres (Penz, 2017), then designers can deliberately use filmic medium and staging techniques within the design process. 'Atmospheric staging', as a paradoxical ideation technique, contributes to the discourse and practice of performative modelling. This perspective greatly matters for the emergence of new frameworks, typologies, and vocabularies based on experiential, transformative modelling characteristics. The aesthetic or the 'atmospheric' register partially determines the frameworks of spatial design, but is usually under-explored or not explicit. If we consider notions related to atmospheric expression, the foundational definitions of modelling are unsettled. As a result, 'The Atmospheric Staging Studio' aspires to formulate a methodological framework of 'atmospheric staging' that is able to initiate ideas and orient design briefs in both educational and professional contexts. The notions that emerge are formulated as an 'atmospheric staging lexicon' and provide foundations for a performative modelling practice.

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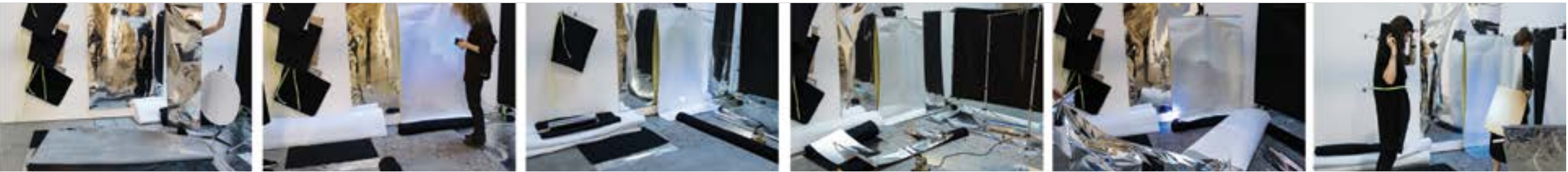
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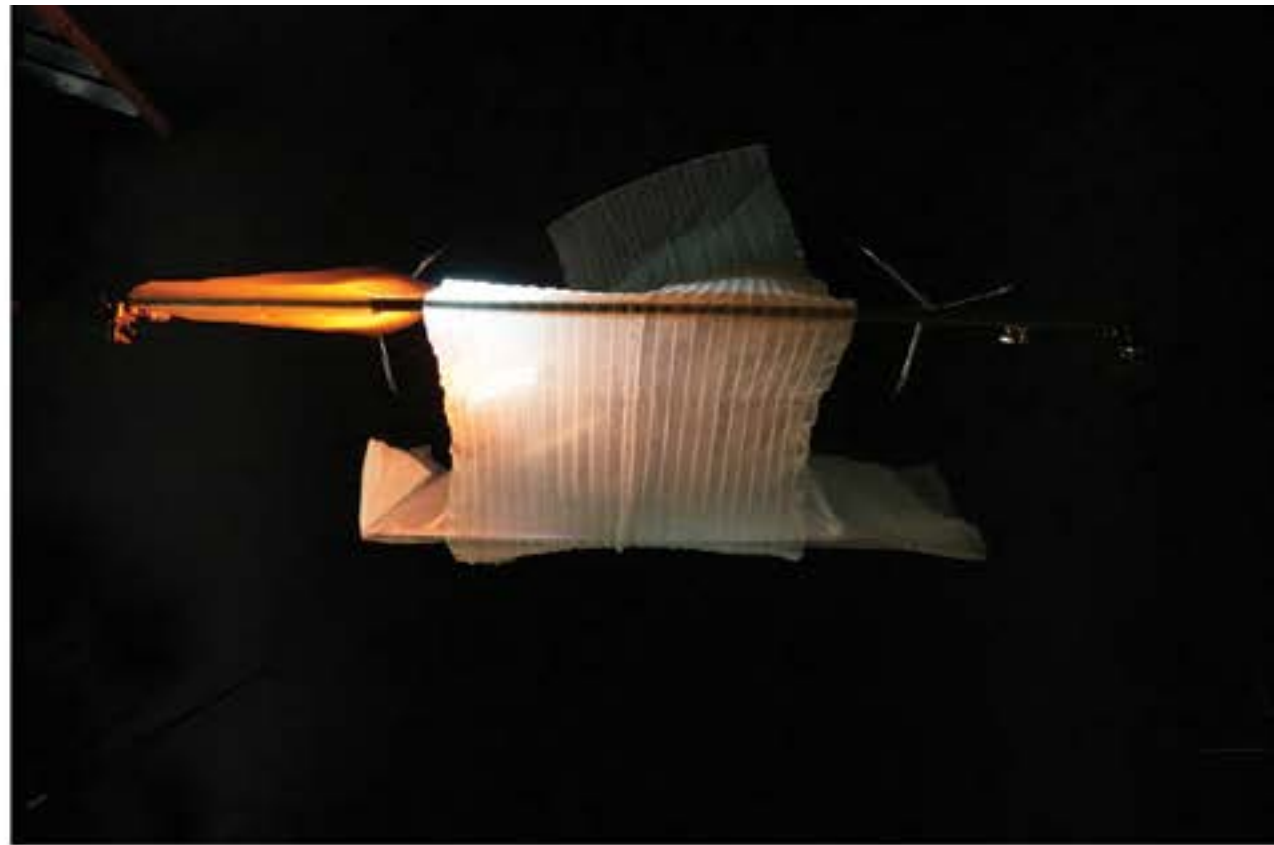


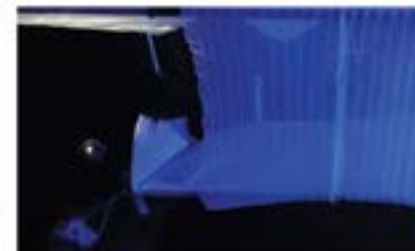
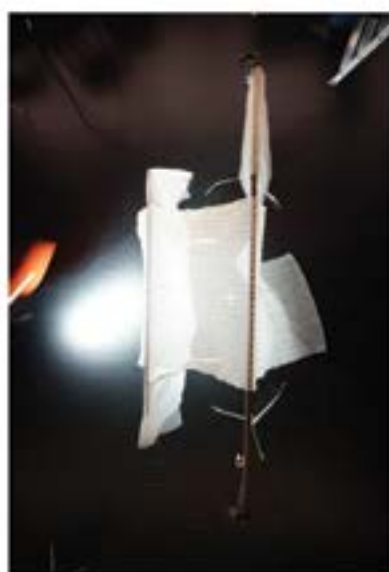














## An investigation of e-Textile interaction design with static electricity

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E-mail, e-book, e-banking– the ‘e’ prefix is commonly used today to signify electronic or online versions of existing products or systems. E-textiles, too, follows this idea to indicate that there is something electronic in textile materials. However, e-textiles as a field of research does not simply encompass electronic versions of existing textile garments or objects. It is not a mere translation of one medium into the other. Rather, it signifies the combination of years of behaviours, material knowledge and skill in two very different yet historically linked domains of textiles and electronics. E-textiles can be said to be a field of study that investigates the integration of traditional textiles with computational elements from the different, often overlapping perspectives of construction, interaction and use.

Computationally enabled textiles, or rather textile-enabled computation offers an exciting design space for re-thinking the role of computers from the perspective of everyday textiles- clothes, furniture, interior elements, or entirely new forms of textiles artefacts. How we handle and interact with textiles is often very different from how we interact with common electronic devices– we perform a wide variety of actions with textiles such as folding, stretching, turning-inside-out, which may not be supported by other devices. These everyday handling of textiles provide a rich resource of material-specific interactions that enables new ways of engaging with computational things that would not be possible with hard devices(Gowrishankar, Bredies & Ylirisku 2017). This inquiry into textile-specific interactions for designing and developing new forms of soft computational things is what I broadly refer to as e-textiles interaction design.

Besides being soft, flexible and comfortable, some textiles present another interactive quality that is meaningful for electronics- the tendency to get electrified when in contact with the human skin. We have all experienced this kind of electrification, for example, feeling our hair rise while removing a woollen cap or hearing sparks when taking off a polyester shirt. This is known as contact electrification, triboelectricity or more commonly as static electricity.

Static electricity is usually considered hazardous in the contexts of both textiles and electronics, causing shocks or damage to electronic components. However, recently static electricity has gained interest in the fields of energy harvesting(Harrop 2016), e-Textiles (Post & Waal 2010) and wearable computing(Zhou, Zhang, Han, Fan, Tang, & Wang 2014). There are design projects that explore interactions with static electricity in the environment(Berzina & Tan 2009) and playfully interpret interactive qualities of textiles brought forward by the electrostatic field of the charged materials(Winkler 2010). As a maker and researcher in the field of e-textiles, this electrification process presented an interesting opportunity for shaping a research inquiry into new ways of interacting with e-Textiles within the context of the Arcintex ETN project.

Static electricity as a result of human-textile interactions: The electrostatic series(Ballou 1954) orders different materials according to their tendency to get negatively or positively charged when rubbed against one another (see Figure 1.). Synthetic materials such as polyester, plastics and Teflon have a high tendency of getting negatively charged when in touch with human skin- I call these electrostatic materials. Thus, humans in contact with everyday electrostatic materials (see Figure 2.) become potential sources of static electricity.

A triboelectric generator circuit(Karagozler, Poupyrev, Fedder & Suzuki 2013) is used as a template for designing and observing interactions between people and textiles with static electricity (see Figure3.). This circuit has two electrodes or conductive elements with one of them insulated with an electrostatic material. The two electrodes are connected to a rectifier circuit and an output, for e.g. a LED. When a person rubs against the electrostatic material while in contact with the open electrode, the electrostatic charges generated through the interaction flow safely through the body and into the circuit enabling the flow of electricity and lighting up the LED in short bursts. In this setup, the person plays a crucial role in connecting and moving different kinds of materials and human skin is integral to the electrical setup that enables the circuit to work. In this way, the configuration of different materials and movements within a triboelectric circuit for generating meaningful electrical signals becomes an interaction design problem. This triboelectric circuit can be explored at different scales and set-ups to envision a variety of interactions with textiles and interior spaces.

Interior textiles as electrostatic generators: The triboelectric circuit could be shaped



into a textile substrate to support the regeneration and flow of electrostatic charges from our everyday interactions with textiles. Existing textile manufacturing techniques, such as weaving (Gowrishankar 2017) or tufting can be used to introduce conductive electrodes insulated with electrostatic materials. Figure 4. illustrates some examples of electrostatic (or e-static) textiles made from weaving and tufting with different strategies for incorporating conductive elements to form the triboelectric circuit. Conductive elements such as metal fibres or coatings are often added to textiles as an anti-static measure aiming to minimise contact electrification and generation of electrostatic charges (Crow 1991). The e-static textiles, on the other hand, follow a pro-static approach where conductive elements are added in a way that direct the electrostatic charges through a circuit rather than dispersing them to the ground. Everyday interactions with e-static textiles, such as rubbing one's feet on the carpet or stroking the tapestry on the wall while walking, can be used for generating small amounts of energy. Achieving this vision demands the development of new technologies that are able to use this electrification process more effectively for e-textile applications. Moreover, non bio-degradable materials such as plastics and synthetic fibres having desirable electrostatic properties, can be recycled for e-static textiles manufacturing.

e-Textiles as spatially-distributed material systems: The triboelectric circuit when interpreted as an immersive spatial setup, represents an interior space where the body in movement with soft electrostatic and conductive materials supports contact electrification. An experimental setup called the electrostatic cube (see Figure 5. & Figure 6.) illustrates some examples of material configurations and immersive e-static interactions. The 2.5 cubic meter large installation acted as a stage for exploring different ways of distributing the materials that make up the triboelectric circuit in space. These in turn guided the choreographies needed to electrify the set-up. The interaction between the body and the electrostatic materials transformed an otherwise dormant interior into an electrically-active object.

Taking this idea forward, the electrostatic cube can be seen as an immersive e-textile object with a distributed material system that is made coherent through human interactions. For example, the textiles themselves may not carry any electronics on their surface, however the whole space comprising of the textile, the conductive elements and a processing circuit along with the person can be interpreted as an e-textile. Working with static electricity and textiles thus calls for an approach to e-textile interaction design which focuses on how the person may interpret connecting

or collaborating with different material qualities embedded into the interior space. As in the case of the electrostatic cube, where the same set up enables different ways of moving in the space to light the LED, embedding potential for interaction rather than rules for interfacing allows creative interpretations in e-Textile interactions and encourages the users to find their own ways of linking different material qualities and activate the space.

e-Static textile interactions as a long-term everyday activity: High voltage but very little current is an aspect of static electricity that places a considerable constraint on how it can be electrically interpreted for e-Textile applications. However from an interaction design perspective this constraint presents an opportunity to consider a different treatment of time and material in interactions. The difficulty of directly using the power generated by the interactions to run bigger devices or components forces one to think in the long term- where not a single interaction but rather a series of them over a longer period of time would be recognised by the e-textile. Familiar textiles-involving practices such as sleeping could become a slow everyday effort for engaging with static electricity over a long period of time (see Figure 7 as an example). Different social implications can be envisioned on the basis of everyday e-static interactions: for example, collecting electrostatic charges from textile interiors may become an energy-conscious sport forming a new community of urban energy-farmers who share experiences and tips on building e-static setups or skin-care products for maximising static electricity; or electricity could become such a precious commodity that spaces such as doors or staircases in every building will be fitted with e-static textiles so that everyone who passes through is forced to contribute some electrostatic energy.

These speculative narratives based on body-material interactions provide an approach for interaction designers to address and discuss the long-term implications of physical choreographies introduced by emerging technologies at an early stage of design. Digital interface design is often about immediate feedback loops. The idea of accumulated interactions provokes interaction design to adopt a long term view- from the time scale of a single human being to perhaps an architectural scale of several centuries. This shift in perspective emphasises sustainability of digital interactions and challenges our expectations regarding upcoming e-textile technology.

Taken as a material quality of e-textiles that needs to be supported through interactions between humans and textiles, static electricity opens up new ways of making,

acting with and relating to e-textile artefacts in the everyday. A prototyping board is being developed to enable further research in this area and engage the e-textile community in exploring and building on e-static interactions (see Figure 8). The board makes it possible to easily incorporate high voltage inputs from electrostatic set-ups to visualise the generated electricity, to interpret it as a sensor to trigger different functions and create e-static interventions in the everyday to prototype long-term interactions.

A textile setup to make static electricity observable: A person can enable the flow of electricity by being in contact with the two electrodes via an electrostatic material. Within this interaction principle, there exist several ways of engaging and moving with materials to enable the flow of electrostatic charge through the circuit.

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Figure 1. Triboelectric series: materials listed according to their tendency to gain or lose electrons. (Figure of the table redrawn from [http://eesemi.com/tribo\\_series.htm](http://eesemi.com/tribo_series.htm))

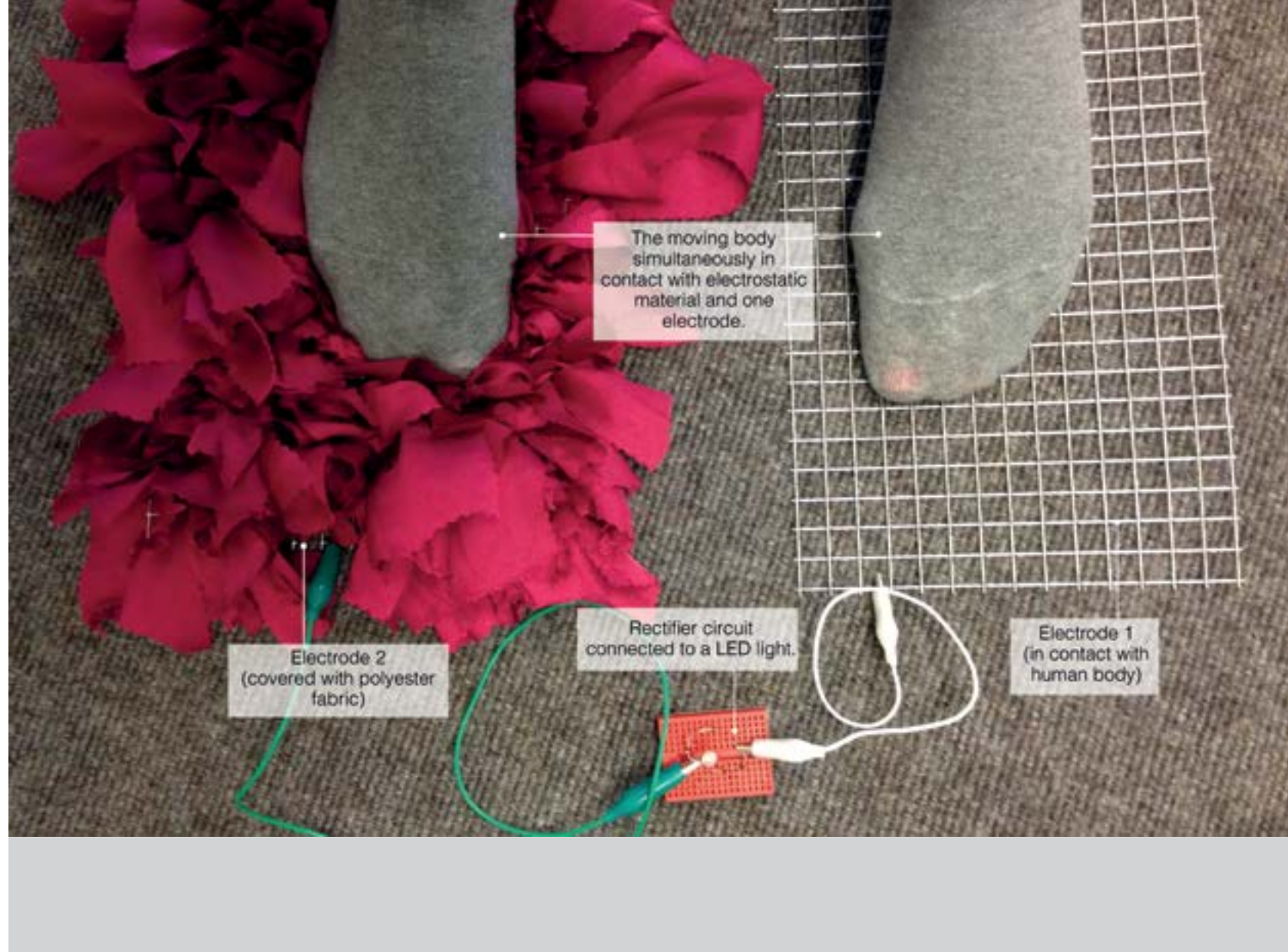


Figure 2. Some examples of soft electrostatic materials and objects from the everyday that have the highest tendency of getting negatively charged when in contact with human body.

TEXTILE PRODUCTION TECHNIQUES used to combine conductive & electrostatic materials.

TUFTING



Alternate rows of conductive and plastic loops. (back of textile)



Different materials combined to make soft electrostatic surfaces

WEAVING

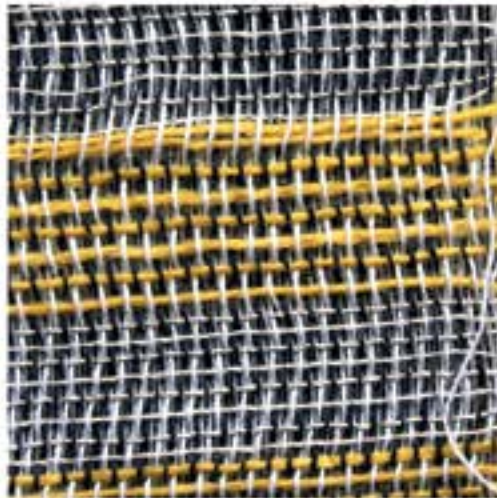


Figure 3. A textile setup to make static electricity observable: A person can enable the flow of electricity by being in contact with the two electrodes via an electrostatic material. Within this interaction principle, there exist several ways of engaging and moving with materials to enable the flow of electrostatic charge through the circuit.

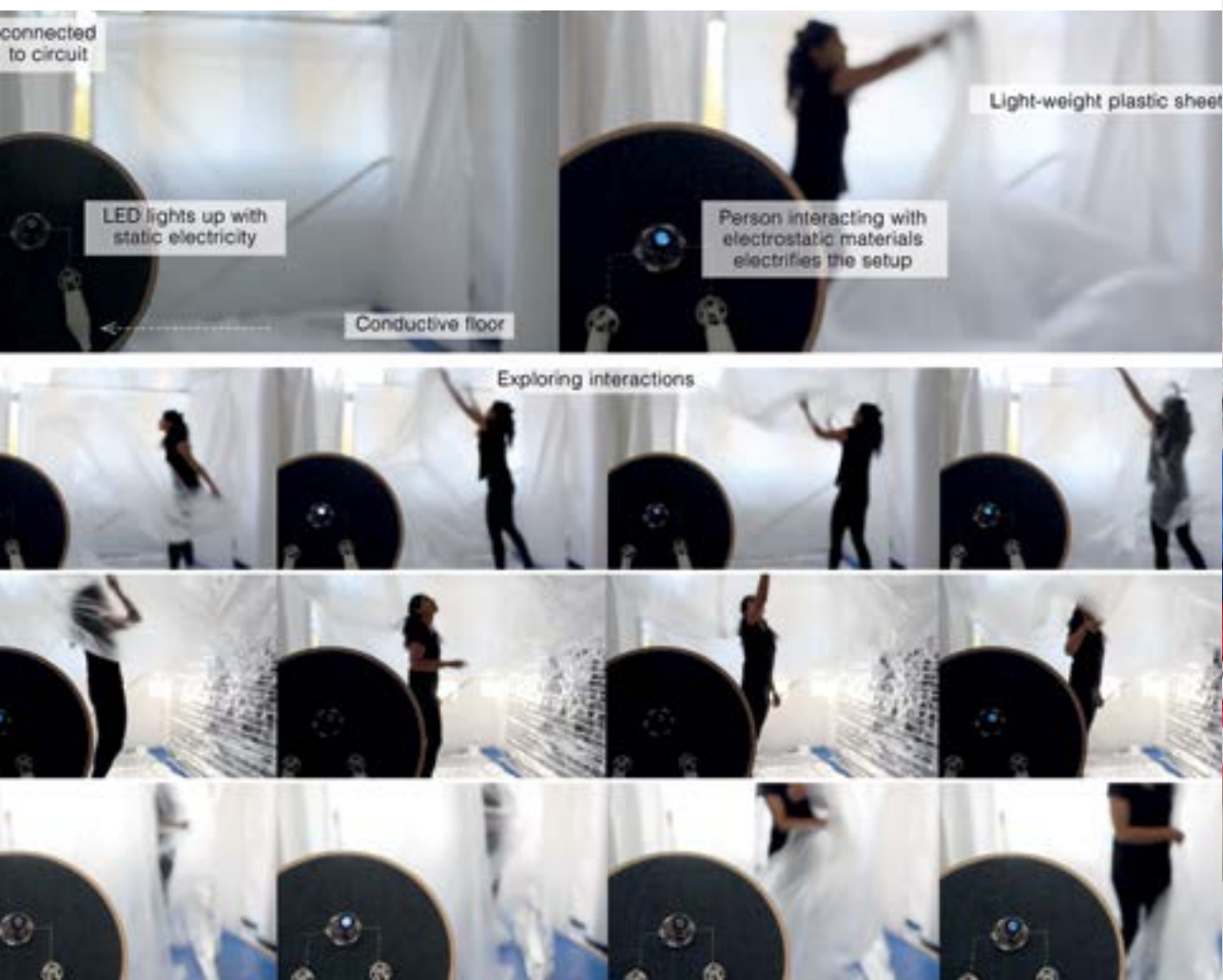


Figure 4. Exploring expressive possibilities of electrostatic textiles: Some examples of material samples that support and enhance the electrostatic effect of interaction, while integrating conductive elements that help to safely transfer the charge.

Figure 6. Details showing aesthetic qualities of interacting with a soft electrostatic material in the interior-setup.



Figure 5. An interior-scale electrostatic installation made for investigating whole-body interactions for engaging with static electricity. This constructed space acts an immersive circuit, in which the person interacting with a large sheet of plastic becomes a component. The blue lights in the foreground mark moments of sufficient electric flow.

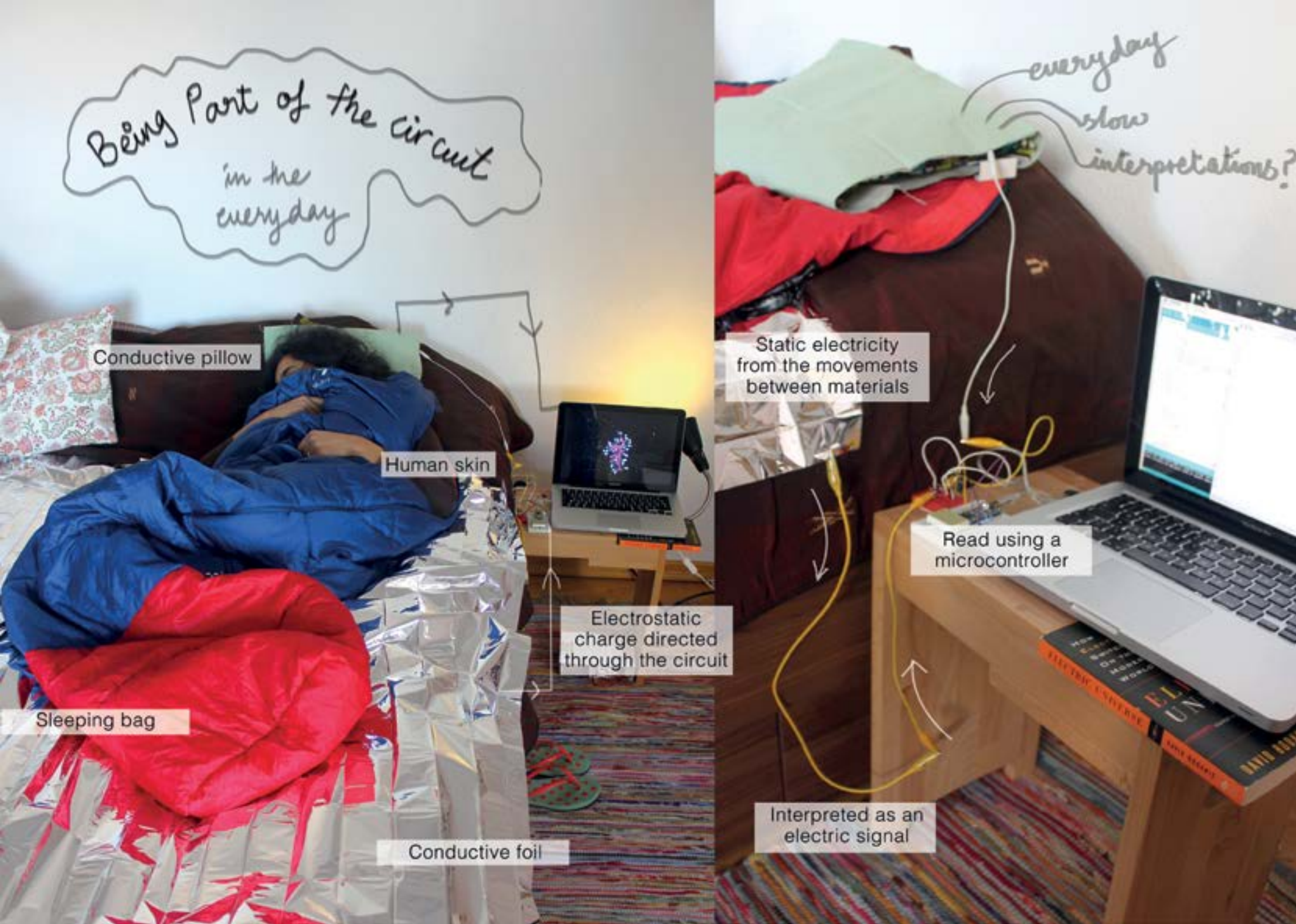
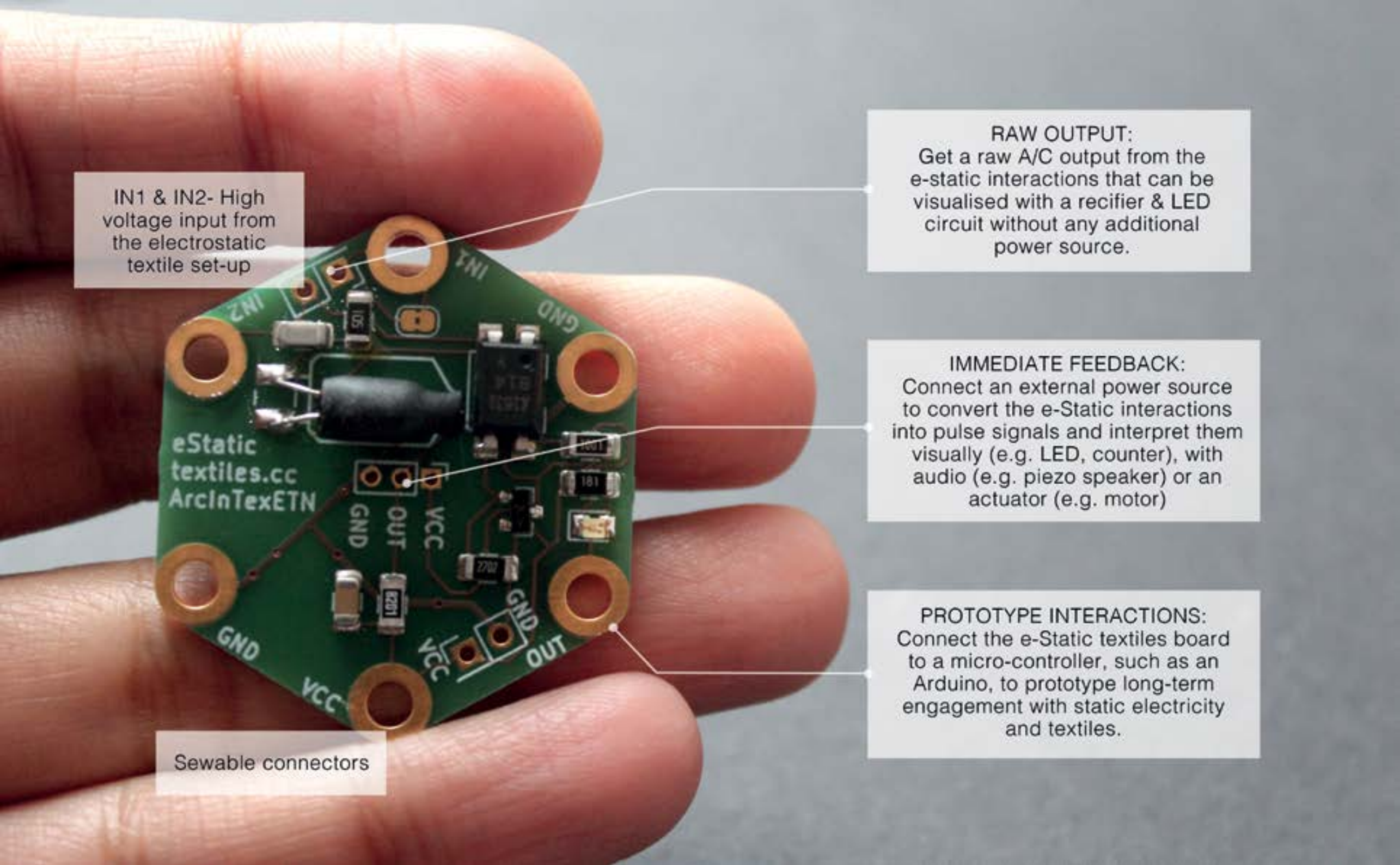


Figure 7. Adopting ways of engaging with static electricity in the everyday to investigate long-term slow interactions. The researcher in the sleeping bag becomes a part of the circuit and essential for the generation and flow of electric charge.





IN1 & IN2- High voltage input from the electrostatic textile set-up

**RAW OUTPUT:**  
Get a raw A/C output from the e-static interactions that can be visualised with a recifier & LED circuit without any additional power source.

**IMMEDIATE FEEDBACK:**  
Connect an external power source to convert the e-Static interactions into pulse signals and interpret them visually (e.g. LED, counter), with audio (e.g. piezo speaker) or an actuator (e.g. motor)

**PROTOTYPE INTERACTIONS:**  
Connect the e-Static textiles board to a micro-controller, such as an Arduino, to prototype long-term engagement with static electricity and textiles.

Sewable connectors

Exempel på bildtext. Placeras 3 mm från bild.

Figure 6. e-Static textiles prototyping board for shaping e-textile interactions with static electricity and textiles.

# THE SCALE OF THE BODY

## Introduction to textile thinking for the design of adaptive and responsive wearables

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Wearable technology design is generally understood as the intersection of functional clothing design and ubiquitous computing. At this intersection of digital computing and analogue dress, digital technologies are used to create new, functional possibilities for dress from multiple perspectives. Many of these are found in areas such as interpersonal communication and entertainment, as well as healthcare and medicine. Technologically, the application of wearables in these areas typically utilises developments in wireless technology, conductive textile materials in fibres, yarns, and fabrics, and flexible and small-scale electronic circuits and power sources (Schwarz et al., 2010). Moreover, as Hansen and Kozel (2007) note, much of this research either builds on the conviction that people's lives can be augmented and improved by a more intimate relationship with technology close to the body, or is motivated by a commercial interest to sell products boosted by technological advancement. However exciting this 'new' field of integrating fashion and technology by e.g. embedding electronics, microprocessors, solar panels, LEDs, and interactive interfaces in fabrics, textiles, and clothing may be, the ways in which wearables have been developed until now too often leave them in the realm of mere gadgetry because they fail in several aspects. Firstly, wearables rarely make it beyond the prototype stage, and do not enter the market because they are not tested through the entire production chain; in other words, they are not robust. Secondly, wearables are seldom 'fashionable', because too little attention is paid to aesthetics in the process of technology design. Thirdly, wearables are not mainly designed with the body in mind or the body as a tool, but are often functionalities added to the textile (i.e. 'smart materials'; see Bavone & Gonzalez, 2012; Seymour, 2008). Another way of putting this is to say that, whereas performance may drive the development of wearables, the performative aspects of wearables themselves are not particularly considered. While fashion's more representational and symbolic aspects are often in focus, central aspects of fashion, such as its more subtle and everyday aesthetic qualities relating to social identity and differentiation through garment technology and expressions, are often neglected. Hence, even though the integration of technology and clothing are considered in relation to the body, it is not so much considered from the perspective of the body.

In contrast to this development, other strands of wearables research put more focus on the bodily and social aspects of wearables to avoid narrow or anachronistic approaches to the generation of new technological artefacts by “widening the range of methods and concepts relevant to the design of mobile, intimate and personal technologies”, as Hansen and Kozel (2007, p. 207) argue. This is achieved by, for example, emphasising the notion of “soft wearables” that “leverage the cultural, sociological and material qualities of textiles, fashion and dress; diverse capabilities and meanings of the body; as well as the qualities and capabilities afforded by smart and programmable elements” (Tomico & Wilde, 2016, p. 1). Drawing on a situationist approach (Debord, 1958) influenced by discourses in relational aesthetics (Bourriaud, 2002), Tomico and Wilde argue for breaking with historical approaches to wearables development based on the human drive for prosthetic enhancement and wearable technology for enhanced communication (Ryan, 2014) by giving the body and context a more central role in the design process (Corness & Schiphorst, 2013). In general, this approach aims for more of a first-person perspective on the design process based on embodied interactions (Tomico et al., 2012) when utilising explorative prototyping for future artefacts and systems (Lim et al., 2008), as well as a first-person perspective on the integration of knowledge from diverse disciplines in the development process through the use of prototypes (Bucciarelli, 1994). As such, this approach is also thought to better connect with particular traditions in the ‘humanities philosophy of technology’ (e.g. Heidegger, 1977) as it opens up for richer interactions that are soft, embodied, situated, and connected (Tomico & Wilde, 2016; Kozel, 2008; Shusterman, 2008; Salter, 2010; Hummels et al., 2008). Above all, however, this development in wearables presents a shift, from wearables as objects (garments) within a system to wearing as an act in a field of interaction.

A focus on ‘softer wearables’ or ‘humanities wearables’ not only makes the body a locus in the research and development of wearables and articulates a greater focus on more performative and phenomenological aspects: more concretely, it also presents a ‘return’ to textiles as both a cultural material and a material with discrete properties that makes the textile material category behave in particular ways. For example, wearables in medicine and healthcare draw in particular on intrinsic textile properties such as flexibility, comfort, wearability, and familiarity – all qualities that open up tremendous opportunities for applications on and close to the body in general (Black, 2007). While material qualities in textiles are important factors in more sustainable design by considering the use of resources and material life-cycles (Lewis & Gertsakis, 2001), knowledge of materials from design perspectives is equally central

in proposing new, suitable ways of living. Similarly, research has discussed how textile practices and knowledge, or ‘textile thinking’, has the potential to develop new materials, new material systems, and new forms (Igoe, 2010; Spuybroek, 2005). As Igoe (2010) argues, textiles involve aspects of art, craft, and technology, indicating that textile practitioners possess both a personal and collective tacit understanding of a specific blend of knowledge. However, as Kane and Philpott (2013, p. 1) argue, “the unique intelligence of textile thinking and the material culture it informs is often overlooked due to the tacit nature of the knowledge involved, which is often stored in the hands of the practitioner or embodied in the resulting textile artifacts”. Other reasons for the overlooking of textiles as a system of thinking with significant potential for societal change may include the fact that it is a relatively low-level and non-digital technology, its traditionally low status among the arts (Auther, 2008), its close connection to ‘fashion’ as an often-questioned and private area of design (Reimer, 2016), textiles’ affinity with ‘home’ decoration (McNeil, 1994; Betsky, 1995), or the simple fact that textiles and clothing are associated with principles of decoration and the female gender, in opposition to traditionally masculine-associated structuralism (Rendel et al., 2000).

Nevertheless, while it is true that textile and fashion design is traditionally often constituted in a first-person perspective, it provides links for connecting ways of living with spaces of living (Wigley, 1995; Leach, 2006). Textile thinking provides the foundations for the ways in which we dress ourselves and our living environment, from first-person perspectives to third-person perspectives. This combination of intimacy and close connections with complex bodily interactions, in relation to patterns of adaptation and responses inherent in textile structures, opens up for concepts and design programmes that have direct implications for changes in forms of living, issues of well-being, and computational technology as not an add-on, but an integral material in clothing and fashion design.

However, with regard to the development of textile thinking for new ways of living in relation to the body and wear, opportunities and challenges lie in the foundations of textiles and garments, where basic definitions and methods remain largely unexplored (Thornquist, 2014). For wearable technology design, soft wearables, or simply ‘wear’, such opportunities and challenges therefore start before known garment types, accepted fashion language, and acknowledged fashion discourses. Exploring and understanding wearable technology design or wear as a qualitative intermediary between body and space in order to concretely affect our ways of living may very

well require a fundamental shift in dress, from more formal definitions such as wear to more interactive definitions of wear as 'wearing'. In turn, this also means that traditional fashion design processes need to be explored and developed to consider and integrate these new technologies and new types of interactions in order to understand and design new bodily interactions.

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DESIGNING ADAPTIVE AND  
RESPONSIVE CLOTHING  
(FASHION DESIGN)

## A Sonic Fashion System

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The body is rarely seen without clothing; dress and the body are closely connected. The body has many possibilities for adornment. Body modifications are the alterations to the body itself that relate to all five senses. The modifications change visual appearance, movements, sounds, and odours. Body supplements can be wrapped, suspended, or pre-shaped; inserted, clipped, or adhered; or hand-held. They can be temporarily or permanently modified in ways that change the perception of the body by oneself or by others (Eicher, Evenson & and Lutz, 2008). Adding tattoos, cosmetic surgery, a tan, cosmetics, perfume, piercings, or scars can modify the body. This can be cultural body modification, e.g. a corset or Chinese lotus feet, which are formed by foot binding (Damhorst, 2005), or an eliminative process of the body or bodily features, such as hair removal, cosmetic surgery, or particular ways of dressing the body.

Fashion, as an interactive expression of dress that is constituted by the body, space, and time, is a predominantly visual culture made up from layers of matter and perception that together construct a multitude of identities, presented and negotiated by individuals in a socio-material world (Merleau-Ponty, 1962; Entwistle, 2000; Noland, 2009). When we are layering our (usually) fake identities to create an impressive composite we do so visually, through clothing and media, where clothing and accessories are central. When we are re-inventing ourselves with cosmetic surgeries and hiding our age with make-up, we do so to be perceived visually in real life, through a fashion shoot, or via visually based social media. Although sound, touch, and smell are elements of clothing and valued from a broader interactive perspective, the visual properties of clothing are so predominant in fashion and fashion education that it is essentially understood as a system of visual components. As a consequence, fashion language is a visual language that opens up for certain expressional possibilities but neglects others: It includes certain communities, but at the same time excludes others.

An important question is thus how to rethink fashion as something else than a visual-material culture. For example, what if fashion language or the fashion system were instead, or also, a sonic fashion language and a sonic fashion system? How would we for example design – fashion – embodied sounds and sonic clothing? What kind of so-

nic silhouettes would we create? How could a sonic fashion landscape be perceived, and sonic fashions change over time? Would we have a murmuring wardrobe? And a shouting wardrobe? How would we listen to sonic clothing? Or, expressed differently, who am I if I cannot see myself? How would we introduce ourselves if we could only hear? And how would we perceive one another if we could only hear?

Aural experience and sound thinking, in contrast to visual experience and image thinking, change the fundamental manifestation and perception of a dressed body: from looking and being seen to listening and being heard. For example, looking at and listening to a body that is wearing high heels are fundamentally different experiences. Moreover, sound is invisible, abstract, intangible, and ethereal. Unlike vision, it is not specifically directional; by contrast, it surrounds our bodies omnidirectionally, effecting a kind of 360-degree bodily extension. This, along with the invisible 'form' (you hear a sound from a distance, without seeing it) and circularity (circular, repetitive structures with no obvious beginning and end) influenced the notion of the 'sonic silhouette'. Although sound is ephemeral and spreads in all directions, its source can be identified. When the sound of steps in shoes is heard, the ears can pinpoint the source of the sound – it is a pair of feet. Walking in shoes and closing or opening fastenings such as zips and Velcro create the rhythmic patterns of sonic silhouettes.

Although identity in fashion is primarily visual, this does not mean that the creation of a sonic fashion system involves starting from scratch. Already different sounds add – intentionally or not – another layer of expression, and could be considered as another part of the constructing fashion and also the self in self-fashioning practice. If you close your eyes, you can hear other people talking, breathing, walking, etc. Similarly, the sounds of clothing also come into play: you can hear how metal bracelets bounce when an arm is moving, the zipping or unzipping of a synthetic sports jacket, the electrostatic sound when someone is taking off a knitted sweater in the winter, the sounds of high heels and sneakers. However, auditory and visual perception are very different: sound is invisible, while pictures are visible; hearing is spiral, vision is directional; hearing immerses its subject; vision offers a perspective. Unlike the sense of self received through ocular reflection, the sonic self is always already mobile, spreading outward whilst incessantly referring back. It is an echoing 'image' (felt throughout the body), rather than one perceived externally as visual mimesis. Similarly, and in opposition to visual fashion, a garment does not make any sounds when it is hung up. A sonic fashion language does not arise without body and without dress. Clothing starts to make sounds, that is, the sonic fashion language

arises through interaction with a human body; when we wear clothes, scrunch them, undress ourselves etc.

A sonic fashion programme could be thought of in at least three parts. First of all, sonic aspects exist on the fundamental level – frictional (natural) sounds and can be studied through experimental studies of the relationship between the moving body, clothing, and sound. The act that creates a sounding silhouette is wearing, which is understood to be the interaction between a subject (a body) and an object (an item of dress): dressing, undressing, walking, sitting, touching, etc. In a way, wearing becomes a means of perceiving a material through the sounds of contact. Interactions between body and sound are based on touch and movement, and so are always kinetic-haptic. In this way, fashion becomes active (a sound) rather than static (an image). This part can be investigated through physical interactions between different kinds of clothing and systems of clothing, where the sounds expressed are recorded. In addition, experiments can be conducted by adding sounding objects to existing clothing for exaggerated expressions. Here, the clothed body becomes a sonic event. If one attaches e.g. a sounding object/accessory to a moving body, the sound extends it. The attachable sounding object is amplifying and choreographing the movements differently; sounds echo bodily rhythms the bodily rhythms become an echo of a particular sound.

Secondly, exploration of socio-material identity can be conducted from visual and non-visual perspectives, wherein the notion of identity is analysed as a construct of the visual and sonic self. In this part, cultural sounds are conceptually explored. For example, in living up to a cultural ideal of femininity, Japanese women rarely lift their feet, instead taking short steps and scraping their feet against the ground. Similarly, in the 1950s North American men often strode forcefully, which was enhanced by the sharp metallic noise made by the cleats that were often attached to the bottom of these men's shoes (Eicher et al., 2008). In relation to such culturally associated sounds, sonic identity was analysed by conducting interviews with visually impaired individuals.

Thirdly, speculative design methods can be used to explore the sonic possibilities for future fashion by shifting the focus from visual to sonic perception. This could then be undertaken to explore different listening modes, perspectives, and practices through experimental workshops on listening, considering the question what – and who – we listen to through the sonically dressed body. Exploration of such different

listening modes can be conducted by using low-tech and high-tech sound amplifiers for bringing awareness of sound and shifting focus from visual to sonic perception.

A research programme into sonic fashion broadens our conception of fashion aesthetics by presenting a new direction for the fashion design field; a non-visual aesthetic that is based on sonic expression, wherein sound is considered to be a design/design-thinking material and an alternative way of defining a silhouette. The results could serve as starting points for introducing sonic fashion and moving towards sound thinking and audial awareness. Furthermore, the primary taxonomy of sonic categories could be used as a means of analysing the sonic properties of dress, and as a tool for designing with sounds. A sonic fashion archive could be developed into a sonic fashion library for suggesting different sonic expressions for dress. Together, the results could suggest foundational new definitions for an alternative theory of fashion – a sonic fashion that includes new fashion design methods where current design tools are reconsidered from a sonic perspective.

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### Towards Ultra Personalized 4D Wearables

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What happens when data is used to generatively craft clothing and accessories for a specific person? The work of Troy Nachtigall looks into the bespoke traditions of shoemaking and explores the scaffolding of bespoke craft and digital technology. Bespoke tailored clothing and accessories are made to the style, form, and behavior of an individual. The design considerations of bespoke attire are interpreted through a skilled artisan craftsman who expresses style in a symbiotic relationship. Fashion Designers often dream of a forgotten age when things were handmade, and everybody wore personalized shoes and apparel. This idea is a myth. Bespoke and tailored garments have always been held in the hands of the economically advantaged. If we look closely into history, we find evidence of mass manufacturing as far back as the ancient Romans. In excavations of Roman army boots, the same logo is seen on more than half the boot in the Hadrianic period. It can be assumed that there was a sizing system to facilitate the manufacture and marketing based upon the research of Archaeologist Elizabeth Greene (Greene 2018). Despite this knowledge, the myth of a bespoke tailored age inspires designers to create a system of products and services that combine new found abilities to understand data and digitally manufacture new garments that are bespoke and tailored.

Digital Fabrication (Gershenfeld 2012) and Data-Enabled Design (Bogers et al. 2016) change the ways in which we design the things around us, including our clothes and shoes. Systems of mass-manufacturing left over from World War II are giving away to new systems of mass-customization (Graciá & Winkelheus 2016) and ultra-personalization (Bhömer, Tomico & Wensveen 2016). Most people engage with fashion as everyday design process where clothes, shoes, and accessories are combined in unique ways. Internet-enabled technologies are changing how designers, makers, and users understand what attire they need, how this need translates to an artifact, how data about the person or product is stored, and how the user interacts with their everyday objects. User's personal data becomes the parameters for algorithms that generate new things. What evolves is a complex adaptive system which is confronted with a "Research through Design" (RtD) approach to understand Ultra-Personalization

using textile structures and textile thinking. The results were 4D printed shoes which served as a vehicle for inquiry into the future of product service systems for bespoke fashion.

Additive manufacturing has been a research topic since the 1980s. A seemingly exponentially growing number of research programs and projects have explored its potential use in different disciplines, academically and commercially (Ballagas, Ghosh & Landay 2018). Attempts to apply additive techniques have also been made in footwear and also gained commercial attention. However, despite efforts by companies such as Adidas, Nike, Under Armour, United Nude and others (The Verge 2017), 3D printed shoes are still somewhat scarce. A possible reason for this scarcity of 3D printed shoes may be that all of them appears to be designed by a fascination with the additive technology itself, and less by the possibilities additive technology has for adaptive manufacturing through which comfort and style can address.

Shoes are often still designed with pen, paper, and lasts (a generic shoe form based upon a general sizing system). Bespoke shoes require that the shoe last be created to the foot, movement, and style of each person. The artisan gathers the "data", then translates in an often implicit process known only in the hands of the artisan. This means that working with data and materials in shoes from a tradition of textile craftsmanship with the digital technology of today could lead to a new understanding of how designers could create new levels of shoe personalization. Textile structures and movement could potentially be translated into computational geometry that was 3D printed in soft and flexible materials.

Taking a hybrid craft (Devendorf & Ryokai 2015) approach to RtD, it is possible to realize new kinds of samples and research products (Odom et al. 2016) that are fully wearable shoes that can be used in everyday life from time periods ranging from one day to two years. A theoretical system of ultra-personalized products and services (Stolwijk & Punter 2018) can further be developed by combining the physical and digital aspects in the front and back ends of the product service system. Such UPPSS systems may also result in evolutions in customer journeys, data flows, and the systemic processes of UPPSS. This type of research also expands the definition of "wearables" to include not only those garments with integrated electronics but also those that are made with data or produce data (Nachtigall 2017). The shoes created would then over the lifetime generate data, much like snow tires, making the shoe into a research product that provided data for all following shoes. The analysis of the data

surrounding the shoe can then allow design to advance personalization and create more space for considering posthumanism concerns such as sustainability. Through a circle Co-Analyze -> Encode -> Co-Design -> Materialize -> Co-Manufacture -> Profile -> Co-Use -> Monitor, research projects like these, explored and developed a designerly understanding of Ultra Personalized Product Service system (UPPSS) (Stolwijk & Punter 2018) that results in research products – shoes – that are actually worn.

Looking at current circumstances, a question that follows the above thinking is “Can a shoe that is personalized to the material, form, and behavior of the wearer be fabricated with existing technologies?” A possible answer lies in 3D printing personalized shoes made with soft and flexible materials for dynamic fit and behavior. This way of printing – designing and manufacturing – would allow the production of a shoe uniquely formed to the user’s feet with material geometries designed to flex with the movement of each foot. By focusing on the materialization process from co-design to co-manufacturing, it suggests that it is possible to produce through hybrid crafting a 4D personalized research shoe. However, questions that remain are still if this could be done for everyone for everyday use? Can personalization exist in a distributed co-manufacturing process?

A project, the ONEDAY sneakers, is a co-manufacturing toolkit that allowed the wearer to make their own pair of personalized shoes in a single day. Each kit included varying levels of tools and materials needed to make a personalized pair of sneakers. 267 users were surveyed before making the shoes and a selection were interviewed two years later. This approach provided a “research project” and “slow design” perspective of personalization over the life of the shoe. The research shows that personalization requires new back end infrastructure to arrive in everyday use. Solemaker, is the name of another core research vehicle, that similarly has resulted in a system where anyone worldwide could generate the files and instructions needed to digitally fabricate a pair of shoes from [www.solemaker.io](http://www.solemaker.io). Starting as a small piece of code between a design researcher and computer scientist; the project is multifaceted with seventeen stakeholders that explores how shoes could potentially be made iteratively in a cycle of UPPSS.

The contribution of this research can be viewed as threefold. Firstly, it results in techniques and tools for personalization; secondly a new understanding of the relationship between data and materials, and thirdly, it exposes general challenges

in ultra-personalization. In particular, this type of research can provide specific examples of code to control the behavior and other design characteristics of shoes using layered textile-like structures. A central challenge in the research is to understand and write software that supports designers through parametric models that adapts to the digital data from wearers – an issue that indicates the need for new and diverse competencies in design. Additionally, Data harvesting requires stakeholders understand how to gather data and create machine code in relation to the complexity of ultra-personalization and its specific design considerations. Broadly speaking, research in Ultra Personalized 4D Wearables can demonstrate that future digital craftsmanship and working with new data/material design relationships requires transdisciplinary understanding.

An Ultra Personalized Product Service System approach brings new combinations and negotiations of design considerations. These design considerations need to be negotiated at the product, service, and systemic level. In the projects, many challenges were solved, but the specifics of personalization leaves many challenges still open for future designers to solve. It is of crucial importance not to lose sight of some of the central analog and more intuitive human aspects of craftsmanship that are needed to realize hybrid digital craftsmanship. Again, in bespoke shoemaking, the highest form of synthesizing form comes from looking beyond simply adding a series of single measurements, synthesizing movement, posture, balance, and social needs of an individual. Looking at Ultra Personalization from a hybrid craft perspective, therefore, allow us to inform and better leverage new and emerging digital design tools. As indicated in the projects, this way of analyzing, designing, manufacturing and using will beyond doubt have significant consequences for products that are worn and open a new world what it means to be wearing something.

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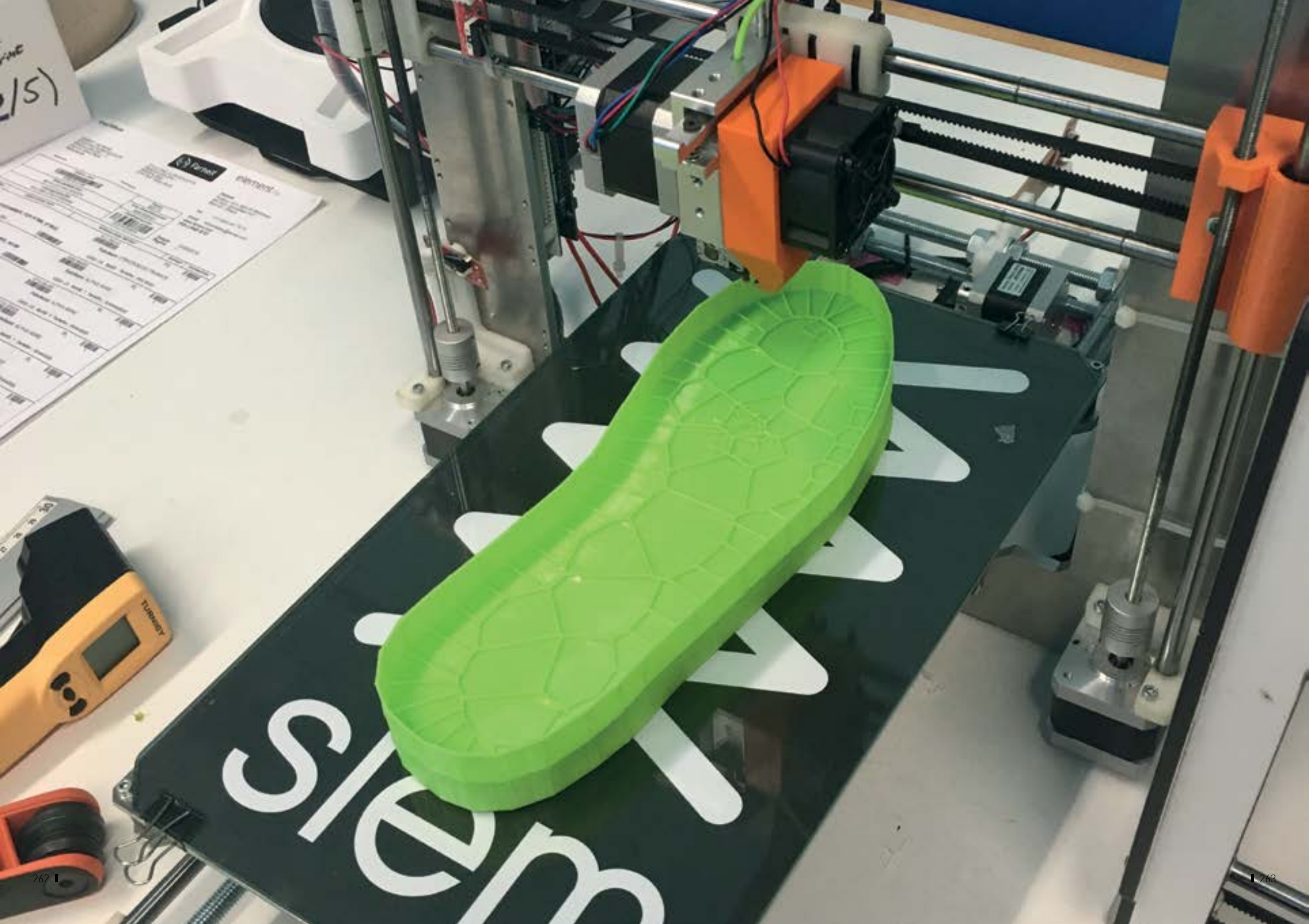










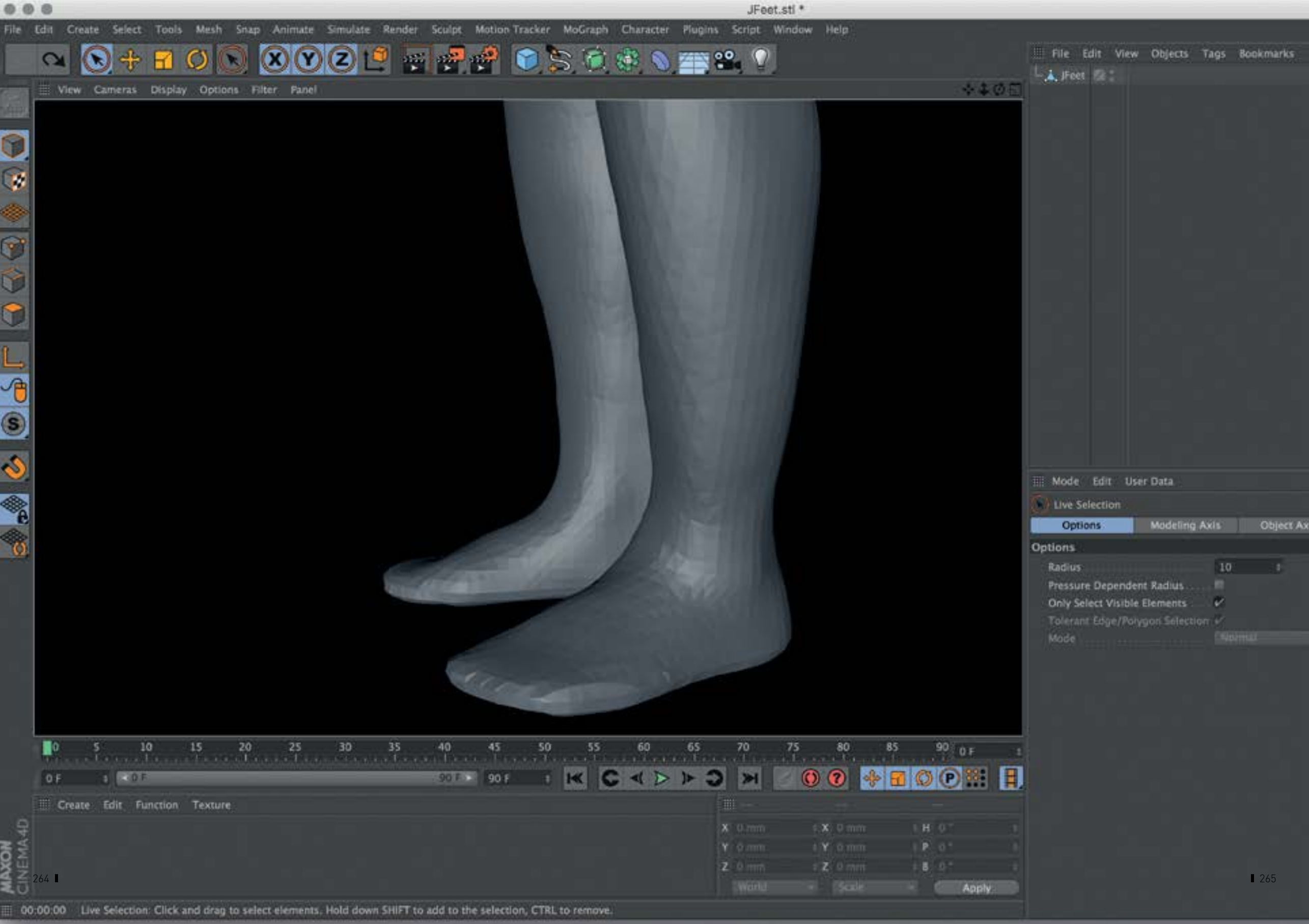


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OBJECTIVE	
METHOD	
RESULTS	
CONCLUSION	
RECOMMENDATION	





Options

Radius: 10

Pressure Dependent Radius:

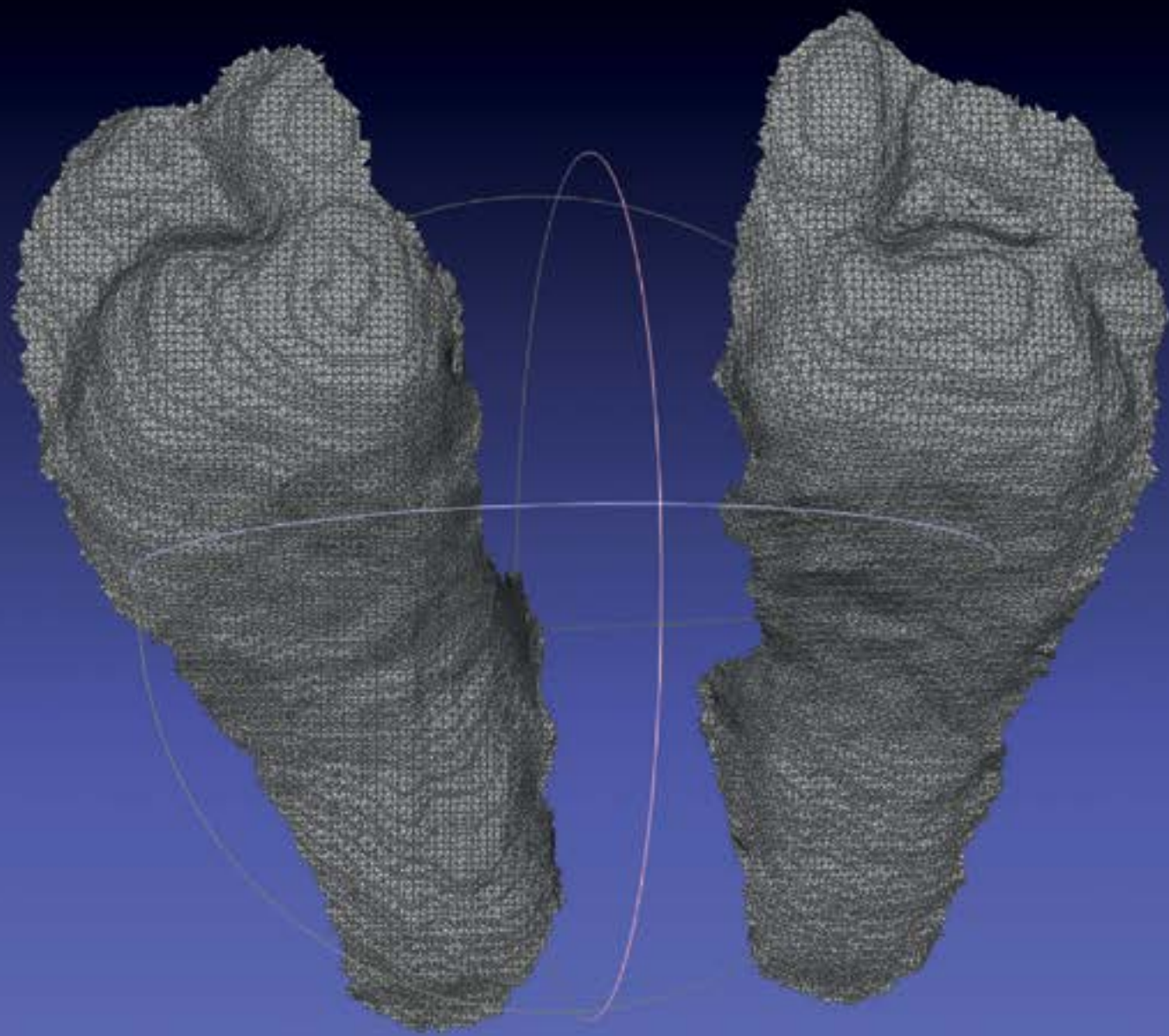
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## DESIGNING FOR ADAPTIVE AND RESPONSIVE WEARABLE INTERACTIONS (TEXTILE INTERACTION DESIGN)

### Wearing Dynamic Fabric

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Dynamic surface-changing textiles have been, and still are, an exciting vision in both science and fiction. While ultra-personalization through design and technology are conceptually at hand and commercially within reach, the notion of computational abilities embedded in materials for clothing and other textile products continues to offer researchers and developers several complex, but inspiring, challenges (eg. (Dunne, 2010; Nilsson et al., 2011; Berglin, 2013).

Over the last two decades there has been a surge of exploration, development and media hype surrounding the integration of various dynamic materials and smart technologies into clothing (Berglin, 2013; Ryan, 2014; Stoppa and Chiolerio, 2014; Toussaint, 2018), widely recognized as the discipline of wearables or wearable technology. Related terminology includes wearable computing, fashion and tech, fashionable technology (Seymour, 2008), techno-fashion (Toussaint, 2018), smart textiles, e-textiles and smart garments. Although the differences between these terms are not always clear, making such distinctions is often required to articulate precise implications and phenomena surrounding the notion of pairing technology with dress (Toussaint, 2018). Yet from the perspective of fashion, it can be postulated that these distinctions need not be made. When glasses, hats, handbags and watches can be seen as functional items embraced by fashion, or even the Walkman and iPod that have been styled as accessories, we see that fashion has always made room for functionality in expressive ways. Despite the potential for a rich relationship between wearables disciplines and fashion, they remain almost entirely separate. Arguably, this gap is exacerbated by the wearables industry focus on scientific innovation and technological developments over concerns related to everyday dress and fashion knowledge.

In relation to this development, a new approach to pairing technology with clothing is on the rise: to examine the potential of an emerging wearable technology outside of its framing as a technology, and focusing on its framing as a material in a garment. From this perspective, the emerging technology would not be analysed for matters of performance, optimisation of tasks, user-friendliness, or novel interaction scenarios, but instead for concerns related to garment-wearing and fashion such as personal



expressivity, style and relations to contemporary culture. A central question is: What design spaces are revealed when an emerging wearable technology is viewed, worn, and worked with as a fashion material in a garment meant for wearing in present day? Choosing the future notion of dynamic, surface-changing fabric as the technological subject of this research (fabric that can visually change like a computer screen), the aim was to understand how this approach could offer insights into the qualities a technology must possess in order for it to be considered wearable in terms of personal fashion—identifying new avenues for technologists and designers to channel their efforts. Although the research takes a critique of techno-centric approaches as its starting point, the findings are meant to inform and integrate alongside technological innovations in the area of wearables.

A first step of inquiry may be to examine the experience of wearing dynamic fabric in everyday life; to examine how dynamic fabric would function as part of the expressive options in a personal wardrobe. In the study, Greenscreen Dress, the researcher wore dynamic fabric every day for an entire year. Without access to an idealized version of dynamic fabric that possesses the properties of a clothing-grade textile and the abilities of a computer screen—she mimicked these qualities by wearing “greenscreen” clothing in conjunction with a chroma-key smartphone app (iDevMobile Tec., 2015). The system allowed live compositing of images and videos onto green garments, acting as a form of augmented reality technology. Engaging in this activity daily, she posted the resulting animated garments on Instagram in order to give them an audience and ensure they had been seen and “worn” in the world in some way. Using auto-ethnographic methods that included daily journal writing, she used her everyday life (Harrison and Mackey, 2016) as the platform for answering specific questions such as What imagery would I wear? When would I change it? Why? How are people reacting? How do I feel? How have my clothing-wearing habits changed? The long-term format of this approach allowed the examination to move beyond the playful, gimmick stage of a new material or technology, and provided adequate time for behavioural patterns to emerge and evolve, as well as to identify certain activities as exceptional (Mackey et al., 2017; Mackey et al., 2017). Selected themes generated from this analysis include styling the temporal form (Vallgård et al., 2015) of surface-changing garments, the expressive interplay and hybrid forms emerging from physical fabrics combined with virtual animations, how situatedness and serendipity created presence for the virtual animations in the wearer’s life, and fostering engagements with online communities surrounding digital aesthetics such as glitch art.

In another study, Phem, the inquiry moved away from the more general question regarding the everyday lived experience of dynamic fabric, to the space of the garment design process. Moving past typical wearable technology tendencies to create one or two garment samples with the integrated technology, the goal was to produce several garments in the context of an entire, exhaustive fashion design process that aimed to launch a fashion collection through photography, social media, and a fashion film. The inquiry took a closer look at the expressive possibilities of dynamic fabric within a contemporary fashion dialogue—one that challenged the fabric to work within mainstream garment trends, styling options, and cultural references that differed from prevalent masculine, sports and/or science fiction-inspired aesthetics presently coming from wearable technology streams. As such, the researcher worked with Pinterest and current runway trends to collect inspiration, a graphic designer, stylist and brand manager, make-up artist, other fashion designers, and the mediums of photography and film to build a fashion image for Phem. The research also examined more precisely her reflections on what it meant to work with the digital/virtual states of the dynamic fabric from the perspective of a materials-based designer, attempting to answer questions such as What is the role of a ‘material’ in the context of fashion design? How does a digital sparkle differ from the sparkling of sequins-embellished fabrics? and In what ways can a designer satisfy their natural urge to rip, pull, fold or tear a fabric that has virtual, intangible qualities?

By placing certain qualities or properties of an emerging technology into different situations, it can be interrogated through its relationship to everything surrounding it. For Greenscreen Dress and Phem, for example, this included relating it to personal expressivity through clothing, mundane practicalities of everyday life, fashion as a socio-cultural tool, and the varying continuums of meaning and practice that new technologies might find themselves a part of. Phem functioned to deepen many of the themes analysed in Greenscreen Dress, but together they highlighted several increasingly important design spaces in the context of working with hybrid physical-virtual forms. For example, both studies revealed particular complexities for working with temporal forms in animated textiles, explored the expressive interplay generated when combining physical and virtual material properties, and demonstrated an engagement with cultural phenomena surrounding digital aesthetics. Furthermore, new insights emerged that included an analysis of how computational dynamic fabrics can work to extend traditional ‘analog’ uses of dynamic materials throughout history. And finally, the research puts forth a call to revisit Schön’s notion of a ‘conversation with materials’ (Schön, 1992) in the context of hybrid physical-virtual fabrics.

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