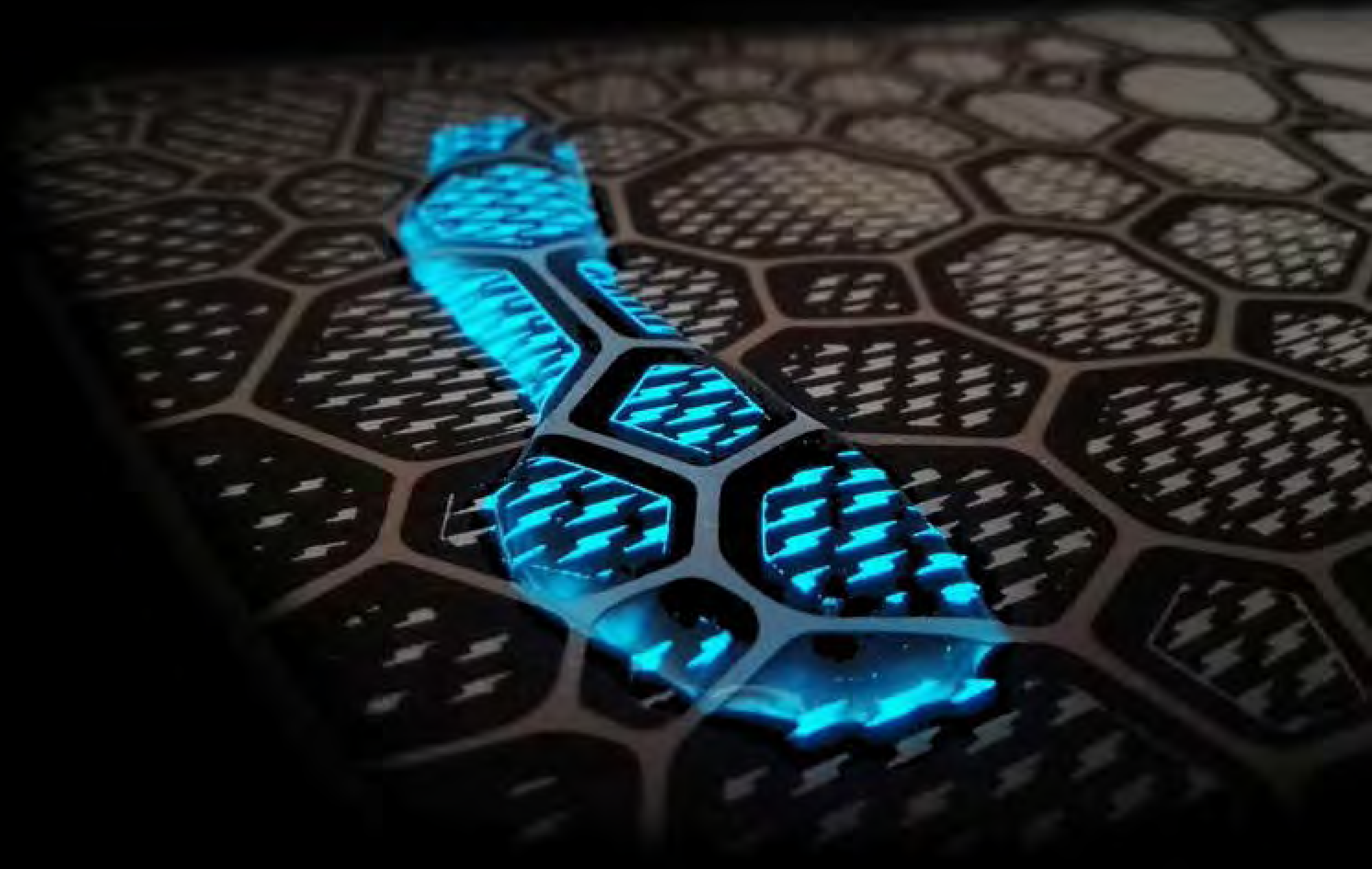
Alive.
Active.
Adaptive.

International Conference on
Experiential Knowledge and Emerging Materials

JUNE 19 - 20,
Delft University of Technology



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on Experiential Knowledge (EKSIG)

Conference Proceedings

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Welcome to EKSIG2017!

Introduction

EKSIG2017: Alive. Active. Adaptive - International Conference on Experiential Knowledge and Emerging Materials of the DRS Special Interest Group on Experiential Knowledge (EKSIG) is hosted by Delft University of Technology.

EKSIG2017: Alive. Active. Adaptive - International Conference on Experiential Knowledge and Emerging Materials aims to provide a forum for debate about materials as a means for knowledge generation by professionals and academic researchers, exploring the role and relationship of generating and evaluating new and existing knowledge in the creative disciplines and beyond. This booklet contains the abstracts of presentations and events constituting the EKSIG2017: Alive. Active. Adaptive held on 19th and 20th June 2017 at Het Nieuwe Instituut, Rotterdam, The Netherlands.

EKSIG2017 Conference Theme

'Material' has been a central point of research and practice agendas for decades in design. In the field of art, Focillon (1934) and Dewey (1980) emphasized the unique role of 'material engagement' in one's process of thinking and reflecting. Material engagement in craft is a means to logically think, learn and understand through sensing and immediate experience of materials (Ingold, 2013; Nimkulrat, 2012; Adamson 2007). Through such practical inquiries one can understand the relationship between material, process and form (Niedderer, 2012).

In HCI, tinkering is an important part of interaction design processes concerned with crafting interactive artifacts that blend physical and digital materials (Zimmerman et al. 2007; Löwgren & Stolterman 2004; Buxton 2007; Holmquist 2012; Sundström et al., 2010). Tinkering with materials is a way of bringing material considerations early into the design process (Giaccardi & Candy 2009). It also has motivated designers to seek an expanded vocabulary to speak of the ways in which digital and physical materials come into relation (Wiberg 2013), describe computational properties (Vallgårda and Sokoler, 2010), and elicit unique expressions through digital materials (Bergström et al., 2011; Isbister & Höök, 2007; Löwgren, 2006; Tsaknaki et al., 2014).

When it comes to product design, many designers in the history of design have explored and engaged the diverse texture and finishing possibilities of materials, alongside phenomenological considerations on the merits of using particular materials for particular products (Manzini, 1986; Ashby & Johnson, 2002; Karana et al., 2014). Today we still see such an approach in some pioneer product design work: see for example the works of Tokujin Yoshioka (paper, glass), Piet Hein Eek (scrap wood), Paulo Ulian (marble), and Alberto Meda (carbon-fibre composites).

Over the last decade, we observe an ever-increasing interest in creating and designing with new materials (Karana et al., 2016; Rognoli et al., 2015; Wilkes et al., 2015). Suzanne Lee uses microbial cellulose composed of millions of tiny bacteria to produce clothing in her bathtub (https://www.youtube.com/watch?v=WVW-jSdhILs); Carol Colette, in "This is Alive" (2013) (http://thisisalive.com), invites us to imagine a world in which plants grow product, and bacteria is genetically reprogrammed; Anna Vallgårda (2009) introduces the notion of 'computational composites', a new design space in which conventional materials (like wood) become more expressive and adaptable through computation. The emergence of such new materials and approaches offers opportunity for achieving new material experiences in design. But as materials acquire new agency and interactional possibilities (whether algorithmic, biological or chemical), how do we work with such alive, active and adaptive materials? And as materials acquire connectivity (whether digital or organic) and thus fluctuate within more fluid situations of use and needs, how do we understand the movements, temporalities and relationships of a material in relation to other materials? This calls for different skill sets, different way of understanding and mobilizing materials in design.

This conference sees a diverse range of researchers and practitioners whose work is centered on the experiential knowledge of working with emerging materials that are Alive, Active and Adaptive.

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keynote talks

Keynote 1
Mark Miodownik

Self-repairing cities

As a result of our greater understanding of matter, the distinction between animate and inanimate matter is now becoming blurred, ushering in a new materials age. Bionic people with synthetic organs, bones and even brains are becoming a reality. Just as we are becoming more synthetic, so our man-made environment is changing to become more lifelike: buildings, objects, materials that heal-themselves are being developed. This talk reviews the science behind these new animate material technologies and considers whether a particular goal, that of creating self-repairing cities, is achievable.

Mark Miodownik is Director of Institute of Making at UCL where he teaches and runs a research group. He received his Ph.D in turbine jet engine alloys from Oxford University in 1996 and since then has published more than 100 research papers. His current research interests are animate materials, innovative manufacturing, and sensoaesthetic materials. For more than ten years he has championed materials research that links the arts and humanities to medicine, engineering and materials science. This culminated in the establishment of the UCL Institute of Making where he is Director and runs the research programme. Prof Miodownik is a well known author and broadcaster. He regularly presents BBC TV programmes on engineering which have reached millions of viewers in more than 200 countries. In 2013 he was awarded the Royal Academy of Engineering Rooke Medal, and he was elected a fellow of the Royal Academy of Engineering in 2014. He is author of Stuff Matters, a New York Times Best Selling book, which won the Royal Society Winton Prize in 2014 and the US National Academies Communication Award in 2015. In 2016 he was awarded the American Association for the Advancement of Science Prize for Public Engagement with Science.

Keynote 2
Anna Vallgårda

Hedonic design

I will argue for a hedonistic turn in design. Hedonism is briefly defined as the pursuit of enjoyable experiences. What makes something enjoyable cannot be defined a priori, only experienced and thus described and reflected upon a posteriori. Indeed, there is no global measure of enjoyableness independent of the view of the subject who experience. Thus, what is enjoyable for some may legitimately not be so for most others. Within the functional paradigm effectiveness and efficiency have been the key motivational values with aesthetics and pleasure only granted a role in as much as they helped optimize the purpose of the design. This is what we could call functional aesthetics or functional hedonism. Genuine hedonistic design, on the other hand, is about designs that enable enjoyable experiences for their own sake. The pursuit of enjoyment may sound superficial at first glance but we can find profound enjoyment in accomplishments as well as in challenging aesthetic and sensory experiences. I will argue how the values of hedonism as a leitmotif will help open new design spaces, challenge our perception of the role of design and designers, and generally provide us with richer and more enjoyable experiences.

Anna Vallgårda is an Associate Professor and Head of the IxD lab at the IT University of Copenhagen. She holds a MSc in Computer Science from University of Copenhagen, a PhD in Interaction Design from ITU, and did a Post Doc on smart textiles at the Swedish School of Textiles. Her research is focused on developing Interaction Design as a material practice. This means she understands and works with the computer as a material for design. In her research, she relies on physical and embodied experimentation with the aim of exploring new material expressions for computational things. Through this practice she also seeks to deepen our understanding of the trinity of forms in Interaction Design: the physical form, the temporal form, and the interaction gestalt.

Keynote 3
Maurizio Montalti

Growing Fungal Futures

One of the main challenges of the current century is to transform our consumption-oriented economic system into an ecologically-responsible, conscious and self-sustaining society. It is therefore paramount to envision and to develop alternatives tackling the urgent issues characterising collective communities worldwide. One of these is identified in waste generation and the subsequent environmental impact originated by oil-based/ synthetic/toxic compounds (plastics), as well as by consumer's behaviour. By entering a direct partnership with micro-organisms (e.g. fungi), a range of novel opportunities is revealed, allowing to envision and put to test a radical paradigm shift, offering a different insight into the objects populating our everyday life and the materials they consist of, as well as into the way production systems could be conceived and reinterpreted. Hence, the mycelia ("root-system" of fungi) of selected fungal species, are to be looked at as the main actors, responsible for favouring the growth of harmless materials, products and systems. A remarkable quality characterising such circular approach lies in valuing existing value chains and organic waste, transforming them into a vast array of novel matters, each characterised by diverse qualities and suitable for different applications. The resulting "cultivated" objects are 100% natural, fully compostable and resulting from waste streams (i.e Circular Economy), tangible signifiers of the way in which materials must and will change in the upcoming future (i.e. bio-technological revolution) and of how manufacturing processes and techniques will modify accordingly. By discussing a number of projects outlining such transformative processes, we will explore and possibly demonstrate how working in collaboration with living organisms and systems can lead to ground-breaking, innovative outcomes. Thus, contributing to positively impact society at large, affecting both industry and consumer's behaviour and balancing the role of the individual with the ecosystem he's part of.

Strongly characterised by a creative trans-disciplinary approach and rooted in a collaborative, research-based and experimental practice, Maurizio Montalti's work tends toward the exploration of the design discipline, aiming to investigate and reflect upon contemporary (material) culture, thereby creating new opportunities and visions both for the (creative) industry and for the broader social spectrum. Maurizio's practice, known under the name of "Officina Corpuscoli", seeks to reveal unorthodox relationships among existing paradigms. By distilling research and analysis and tangibly materialising relevant facts, Officina Corpuscoli's s goal is to create projects and conditions that allow for a resonant critical experience, by the synthesis of ideas through design. To this end, the design process and the subsequent materialisation of concepts are often used as tools and strategies for questioning culture, critically and constructively addressing the design field, as well as targeting industry. Officina Corpuscoli, founded in 2010 and based in Amsterdam, operates as a multidisciplinary studio, providing creative consultancy and developing both commissioned and self-initiated projects, often inspired by and in collaboration with living systems and organisms. The studio's work has been widely shown in multiple museums, exhibitions and festivals, both nationally and internationally. Besides the various activities and projects at OC, Maurizio is the co-founder of Mycoplast, a company focused on industrial scale-up of mycelium based materials, services and products and he is also highly involved in education, currently co-heading the MAD Master at Sand-berg Instituut, as well as teaching, lecturing and mentoring in different national and international academies and universities.

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PARALLEL SESSION 6
Responsive Materials

‘Grow-Made’ Textiles

Professor Carole Collet, Design & Living Systems Lab, Central saint Martins, University of the Arts, London, UK.

Abstract

This paper explores the emergent notion of the ‘grow-made’ by evaluating current work produced for *Mycelium Textiles*, a design research project that investigates the potential for co-making and co-designing with mycelium. Mycelium is the root of fungi, it is composed of a fine network of thread-like branches and is found underground. By cultivating mycelium on a range of substrates, it is possible to grow materials by harnessing its ability to digest and transform cellulosic food into natural composites. This paper will specifically discuss work in progress into mycelium colonisation techniques applied to textiles and their potential to propose innovative patterning processes and slow-grown embellishments for fashion applications. By revisiting traditional textiles and surface embellishment techniques, the project also examines the potential to cultivate the self-assembly properties of living organisms to evolve ‘self-patterning’ textile protocols. Inscribed within an exploration of alternative sustainable fabrication models, the project explores expanded design toolkits and methods for co-making with living systems. Augmented by husbandry techniques, traditional and contemporary textile craft can inform the cultivation of living mycelium for patterning and surface embellishments. Whilst textiles are profoundly anchored in the history of humanity as material and cultural artifacts, they have so far allowed us to navigate both the hand-made and the man-made paradigms. With emergent practices in biodesign, the notion of the ‘grow-made’ is now also possible. What are the implications for the design of our future ‘grown’ materiality? Will ‘grow-made’ materials facilitate the transition to sustainable fabrication?

Keywords

Mycelium; Textiles; Grow-Made; Self-Patterning; Sustainable.

Paradoxically, as we deepen our understanding of the impact of the human species on our finite planet, and as we acknowledge spiraling biodiversity loss and expanding pollution levels, we also witness record efforts to transition towards more sustainable and resilient ways of living: *“While environmental degradation continues there are also unprecedented signs that we are beginning to embrace a ‘Great Transition’ toward an ecologically sustainable future”* (WWF Living Report 2016, p.6). Design has a prescribed function in our manufacturing and consumption models, and therefore has, and will continue to play a pivotal role in shaping our future sustainable materiality. However, production strategies such as recycling, upcycling, optimising energy and material efficiency, and adopting environmentally-aware material sourcing may not be enough in a context of unprecedented levels of human population, and rampant consumption models. Researching alternative design models that transcend the conventional problem solving approach and explore new production paradigms can help transitioning to a more holistic and resilient future. We need to shift away from the so-called ‘Anthropocene’ era, where human activities have begun to impact on the geological planetary forces (Crutzen P, 2007). Rachel Armstrong argues that *“We need to enable the Ecocene – whereby human scale events augment and enhance the living ecosystems of our planet*” (Imhof, Gruber 2016, p. 12). Questioning and reinventing the very materiality we prescribe and script during the design process is becoming paramount to facilitate a transition towards the Ecocene. The research project 'Mycelium Textiles' is very much inscribed within that fundamental exploratory phase and aims at harnessing the qualities of living mycelium to re-imagine ways of growing and embellishing textiles. The design-led development of mycelium materials is a fairly recent yet fast expanding field. The artwork of Philip Ross and design studios like Maurizio Montalti at Officina Corpuscoli and Erik Klarenbeek have opened up a vast array of possibilites to develop new materials, from 3D printing to the recently launched leather mycelium (MycoWorks/Philip Ross, USA). Ecovative, one of the world leaders in mass manufacturing mycelium-based material produces packaging and insulation boards by growing mycelium onto agricultural waste such as corn husks, hence forging the way for circular sustainable models of production*: "The infrastructure, knowledge and technology needed to grow fungal materials are already here and in place. Putting them to work is mostly a matter of reconfiguring and joining together several different manufacturing processes as an integrated system."* (Ross 2016, p. 258).

Textiles is a very impactful, energy hungry and oil dependent industry. Yet we cannot imagine a future world without textiles. Can we develop co-designing strategies with living systems such as mycelium to grow patterns, surface coatings and embellishments that could replace current oil-based textile processes? Can we develop a circular model that integrates local biomass waste for the production of local textiles for fashion? Section one of the paper will contextualize this project within the emergence of biodesign and discuss a critical framework for designing with the living. Section two will discuss the project 'Mycelium Textiles' to date. Finally, section three will elaborate on the emergence of the 'grow-made' paradigm in the context of future textile production and scenarios for circular production.

1 / Designing With Living Systems

In the past decade we have witnessed the rapid emergence of biodesign. This new field of design is driven by an inquiry into future living that arises from the intersection of biology and design.

> *Biodesign goes further than other biology-inspired approaches to design and fabrication. Unlike biomimicry, cradle to cradle, and the popular but frustrating vague 'green design', biodesign refers specifically to the incorporation of living organisms as essential components, enhancing the function of the finished work (Myers 2012, p. 8).*

With biodesign, the mainstream and conventional methodologies for research and development are radically altered by the notion of working with living systems as opposed to inanimate matter. Designers have begun to expand their roles from scripting the form-shaping of existing inanimate materials, to creating and growing new biological materialities.

As a design researcher, I began exploring methods of intersecting biology and design in 2007 as a means to inquire into new models for sustainable design. Apprehending principles of biomimicry led to unravelling the deeper implications of relating to the Natural world as a designer. Whilst grasping the notions of Nature as a model, mentor and measure (Benyus 1997, p. 0) I also became aware of the latest research in synthetic biology, and the unprecedented possibility of coding new genomes and creating new species designed to produce bespoke substances. As these two approaches collided, one emulating the values of life, the latter proposing the 'hacking' of life, I needed to situate the designer's evolving role in working across biomimicry and biology.

> *Mastery of the formation and growth principles that are specific to living organisms has inaugurated a genuine meta-ecology. A profound transformation of the very concept of Nature has therefore been set in motion, which is indissociable now from artificiality, from technical and technological production.' (Brayer, Migayrou 2013, p. 11).*

To address this transformation of our perception of the Natural world, I began to develop a framework for designing with the living that elaborated a critical stance and defines three strategies for advancing biodesign: 'Nature as a Model', 'Nature as a Co-worker', Nature as a Hackable system' (see Fig.1). This framework emerged out of a mapping exercise that led to the curation of the exhibition 'Alive, New

Design Frontiers' held at the foundation EDF in Paris in 2013. The exhibition applied the framework below as a means to engage with a critical lense to review the benefit of biodesign for future sustainable living.

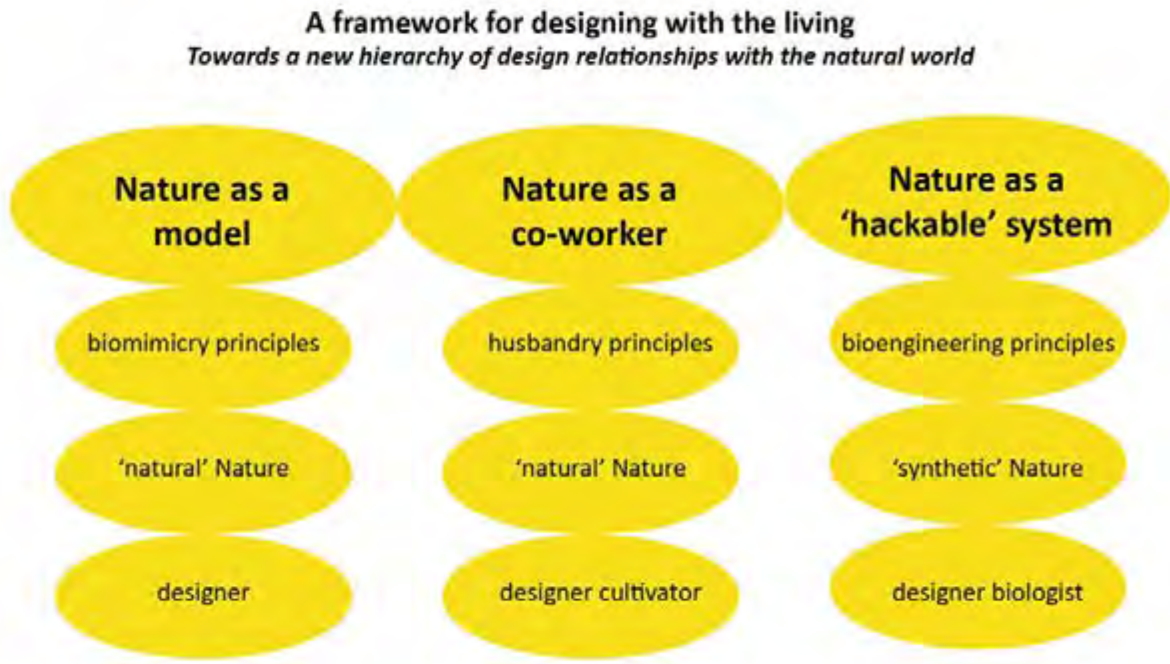

Fig.1 © Carole Collet 2013

Today, the field of biodesign is fast growing, and the fascination to explore biology through design permeates a new generation of designer, eager to engage with new techniques and technologies. Whilst not all biodesign projects are concerned with environmental issues, my design research is ultimately driven by an inquiry into disruptive and alternative models for sustainable design and fabrication. In this context, the three pathways highlighted in the framework above help identify a set of principles for collaborating with the living and help reposition the role of the designer within a sustainable discourse.

The first category 'Nature as a Model', relates to biomimicry principles that endorse the emulation of natural systems, and is based on the understanding that Nature's production system is pollutant free, operable at ambient temperature and relies on a circular cyclic material value system, where the waste of one entity becomes the food of another. The integration of biomimicry principles into architecture, design and manufacture is well established even if not a prominent model yet. Architects such as Michael Pawlyn have demonstrated that the study of the desert beetle can lead to engineering a building that generates its own micro climate. *'For virtually every problem that we currently face – whether it is producing energy, finding fresh water or manufacturing benign materials – there will be numerous examples in nature that we could benefit from studying'* (Pawlin 2011, p. 1). Research into the nano-structure of a shark's skin has led US-based Sharklet Technologies to develop synthetic wall coverings for hospitals that mimic this nano-structure to repel super-bacteria. In textiles, Interface, a carpet manufacturer, has led the way in deploying biomimetic principles to reduce the environmental impact of toxic chemicals used in carpet manufacturing. However, whilst the adoption of biomimicry principles has led to innovative achievements, too often the end-product integrates fossil-based materials and energy in its production chain. For example, Velcro, a material that can attach and detach infinitively and which was developed by mimicking the structure of the Burdock seed, is effectively bio-inspired, but not sustainable as such. It is actually produced in a conventional manufacturing system, and made from non-renewable, non-biodegradable oil-based polymer. So biomimicry, whilst a step in the right direction, does not always lead to sustainability per se, as we too often deploy biomimicry principles in the design phase, but have to rely on conventional production and sourcing in the manufacturing stage.

The second category, 'Nature as a Co-worker', integrates biomimicry principles with biology and husbandry principles and fosters the integration of living organisms in the creation or production process. The project 'Mycelium Textiles' sits in this category. Here the designer goes beyond imitating Nature as a model to become a 'cultivator' and engages with processes akin to husbandry and gardening. By biologising the design brief (Benyus, 1998), the designer sets a protocol for collaboration with a living organism, and thus relies on the inherent sustainable advantage of Nature's method of production. In a more conventional context, a designer will select materials, be they natural or synthetic, to either specify a set of manufacturing processes or to directly work with it, as an artisan. Here the designer engages with form-shaping strategies as the living material grows. The morphogenesis of the end-product is defined a) by the design intervention at the onset and/or during the growth period, b) by the ability of the designer to create and maintain the appropriate conditions to sustain a natural organism alive, and c) by the living organism itself. By directly collaborating with a natural organism (a living factory), the designer can incorporate properties of the living in the production of artefacts. Here, the designer becomes a cultivator, whilst manufacturing becomes 'horticulturing'.

The third category, 'Nature as a Hackable system' is a radical new proposition that emerges from advances in synthetic biology. Synthetic biology is defined by the Royal Society as *"The design and construction of novel artificial pathways, organisms and devises or the redesign of existing natural biological systems"* (The Royal Society, 2016). It is now possible to create new species by writing up new genomes on a computer, which is then synthetized in DNA form, and 'booted up' in simple living organisms such as yeast, bacteria, microbes and algae. By doing so, we can tune these genetically coded living factories to produce a chosen substance. For instance, a bacteria can be reprogrammed to produce biofuel, a yeast can make silk, or vanilla, whilst tissue engineering techniques enable us to grow leather in a lab. Since 2016, the textile industry has access to commercial silk produced by yeast, and companies such as The North Face and Adidas have begun to integrate these new bio-synthetic materials into their production lines. Innovative companies such as Bolt Threads (biosilk) and Modern Meadows (tissue engineered leather) argue that these new means to produce textiles are leading the way in terms of new alternative sustainable production strategies. The paradox here is that synthetic biology is effectively a form of extreme genetic engineering which is taking advantage of natural biological processes, but recoded to suit our industrial purposes. Whilst it is too early to fully assess the sustainable impact of such production, we also need to remind ourselves that currently *"Textiles is fourth in the ranking of product category which cause the greatest environmental impact, just after food & drinks, transport and housingfu"* (EU commission, 2013, p 1). Polyester and conventional cotton are the two most used fibres in the word (Ethical Fashion Source 2016, p. 2), the first is made from non-renewable oil, whilst the latter relies on damaging agricultural and heavy polluting practices with intensive use of pesticides and fertilisers. So any alternative propositions that enable us to reduce the environmental impact of the textile industry are worth exploring.

The following sections will present and analyse current work in progress of the *Mycelium Textiles* project and discuss the emergent paradigm of the 'grow-made' versus the hand-made and the man-made.

2/ Mycelium Textiles – Process and Development:

The project *Mycelium Textiles* is an experimental collection of materials and artefacts that explores the future of mycelium growth as a potential new sustainable surface treatment for textiles. As such the project explores the dynamic forces of a living system and its evolving resulting materiality more so than simply designing predetermined forms to constrain and shape matter.

The aims of this design-led material research are a) to produce both soft and structural textile qualities by experimenting with the environment of growth of the mycelium b) to develop new biodegradable, compostable coatings for textiles that can replace current oil-based finishing processes, and c) to develop protocols that encourage self-expression and self-patterning techniques in mycelium materials. The basic principle of growing mycelium material in a controlled environment relies on the ability of mycelium to absorb the substrate onto which it is growing and to transform it into a composite substance. A mycelium culture is introduced into a sterilised substrate, and depending on the type of culture, the temperature and humidity level, will take several days or weeks to colonize its food. Once the colonization process is complete, the material is baked to kill the living mycelium and to dry the finished material. Simply tuning the parameters of growth will result in a variation of materials. As Philip Ross, an artist and pioneer in developing mycelium-based materials, explains: *"fungi are very sensitive to their surroundings, and by altering subtle factors it is possible to make their tissue express a range of variably determined physical characteristics"* (Ross 2016, p. 255).

The design research project *Mycelium Textiles* uses a range of materials from waste coffee grounds, to agar and natural textile fibres such as hemp, sisal, soya bean fibre, raw silk, organic cotton and linen as a starting point (see fig 2). These foundational materials provide a transformative grid that harness, support or resist the life of the mycelium.

Fig.2: selected range of materials used to develop the *Mycelium Textiles project. Photography* © Carole Collet 2016

The symbiotic temporality of these pre-configured materials interacting with the living mycelium culture results in evolving a variety of surface tensions and textility. The project to date consists of a series of experiments that are derived from traditional textile surface patterning techniques revisited to incorporate protocols for mycelium growth. Methods such as mending, starching, screen printing, and resist-patterning techniques have been re-interpreted and adapted to a new context of use. Examples include:

Tartan Mycelium: Here the classic check pattern is created not by a woven construct of coloured yarns, but by using strips of natural unbleached hemp layered out in a check formation at the bottom of a mould containing waste coffee ground. As the mycelium culture slowly colonized the mould, the hemp strips began to deteriorate and effectively biodegrade. The mycelium incorporated part of the degrading hemp into its growth. After three weeks, the material was removed from the mould to be baked. The result is a striking colour difference with a rusty brown or a black where the hemp strips had been layered, and a white background where the mycelium only had coffee for food. We also notice on this sample a spill out of the mycelium which is overgrown in some part as it escaped the mould it was contained within (see Fig.3, left side of the photograph).

Fig.3: Tartan Mycelium © Carole Collet 2016

Mycelium lace. In this case, mycelium is used as a mending technique on damaged or vintage lace. By colonizing parts of the lace, the mycelium contributes to reinforcing its strength, as much as it can create a surface coating akin to starching, thus allowing to render a host material softer or stronger. By encouraging the mycelium to grow in some parts of the fabric more than in others, the growing skin can act as a repair mechanism (Fig 4). Fig. 5 shows how mycelium is used to create a permanent fold into the lace, this is done by growing mycelium in a part closed, part open mould. Traditionally a permanent fold is achieved by heat-setting a polyester-based fabric, using a paper mould, and is a high energy process. Here, 'growing' a single fold happens at ambient temperature over a period of twenty days. This is now being developed further to achieve a series of folds.

Fig.4: Mycelium Lace © Carole Collet 2016

Fig.5: Detail of permanent fold on Mycelium Lace © Carole Collet 2016

Mycelium velvet: One of the current experiment aims at emulating velvet qualities both in terms of shine and tactile qualities. Current results focus on two techniques: one consists of growing mycelium on a base cloth covered with a fine layer of waste coffee grounds (Fig.7), the other encourages mycelium to grow away from a central food point (Fig.6). While the shine and softness qualities are expressed with these techniques, the samples are not even, and not as fluid as a velvet cloth yet, and experimentation continues.

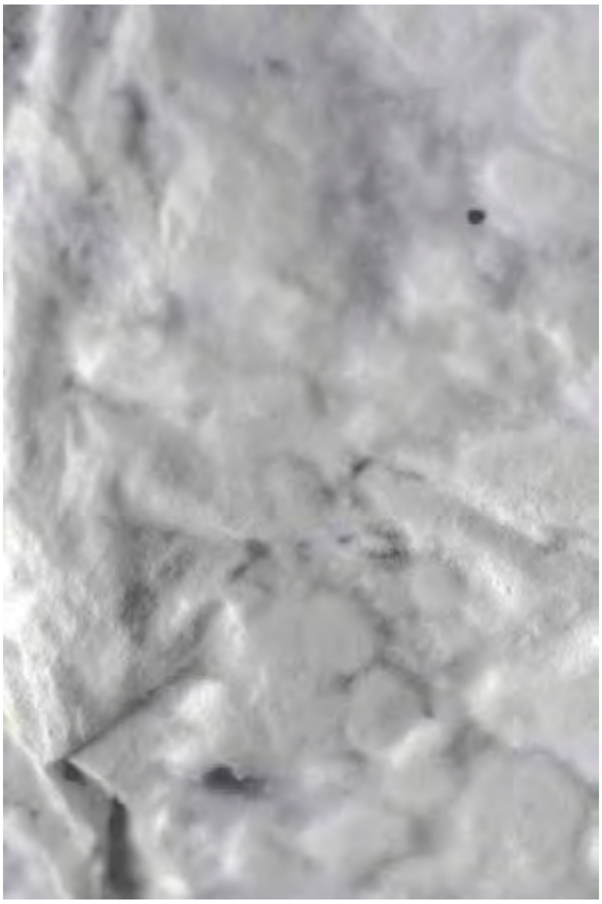

Fig.6 & 7: Mycelium velvet experiments © Carole Collet 2016

Self-patterning mycelium rubber: One of the characteristics of a living system is its autopoietic quality. As the work developed I found that I was as much resisting and combatting self-expressive qualities of the mycelium as I was trying to encourage them. In one experiment I developed a protocol that encouraged the mycelium to manifest its self-organised behaviour in the form of visible patterns, thus exploiting self-assembly qualities inherent to biological systems. As seen in Fig 8 & 9, the patterns, reminiscent of floral designs are actually produced by the mycelium itself, rather than being shaped by a mould. The flowers 'grew' over a period of three weeks on the open surface of the food substrate. In addition, this particular process resulted in the creation of a rubber like material, with very flexible and elastic properties. It is washable and biodegradable (for patenting reasons, the exact protocol cannot be revealed at this stage of the research). Here I have designed the environment of growth, but the mycelium itself created the floral patterns, so who is the designer? Can we speak of co-design in this context? As with all collaborations, it is the evolving creative tension between the partners, or the co-workers that is evidenced in the end-result. In this instance, balancing the act of nurturing versus controlling the growth of mycelium is the role of the designer 'cultivator'. The aesthetic and tactile qualities of the end-product are the result of this symbiotic evolution, not the mark of a predetermined design intention. In other words, the goal was not to attempt to design a floral pattern, but to let the mycelium express itself and take control of the final aesthetic of the material. It so happened that the mycelium expressed itself in a form of fractal patterns, akin to floral designs. This is very much a novel approach for designing textiles.

Fig.8: Self-patterned Mycelium Rubber, showing the flexibility of the material © Carole Collet 2016

Fig.9: Self-patterned Mycelium Rubber, details of the self-grown floral patterns © Carole Collet 2016

The examples above showcase some of the most successful experiments. These rely on a tacit understanding of traditional textile processes, and their creative re-interpretation in developing mycelium growth protocols. But for each successful experiment, there is a range of failed samples which are crucially important in developing new knowledge. Failure is a useful research tool. Each experiment is recorded in terms of process, type of mycelium culture, temperature, humidity level, and light conditions. Each failure helps to reassess the process to evolve new ones. By witnessing the morphologic evolution of the materials and establishing a dynamic dialogue between the design intention, and the dynamic autopoieitic characteristics of living mycelium, new materials can emerge. Below is a range of failed experiments which continue to inform current work in progress. One of the most common issues has been contamination of the samples. The materiality of contaminated samples are defined by dynamic prevalent forces, and by which organism wins the competition for life.

Below is a mycelium culture growing on vintage lace (Fig. 10 & 11) and mycelium culture growing on a cube of agar placed onto a linen cloth with waste coffee grounds (Fig. 12). In both cases, the microbial contamination (visible as grey powdered texture) has covered the surface of the cloth faster than the mycelium has grown, but after six weeks, the mycelium (seen as a white mesh) is starting to fight back and has begun to expand again. Could contamination therefore be used as a resist process?

Fig.10 & 11: contaminated mycelium sample grown on vintage lace and coffee ground.
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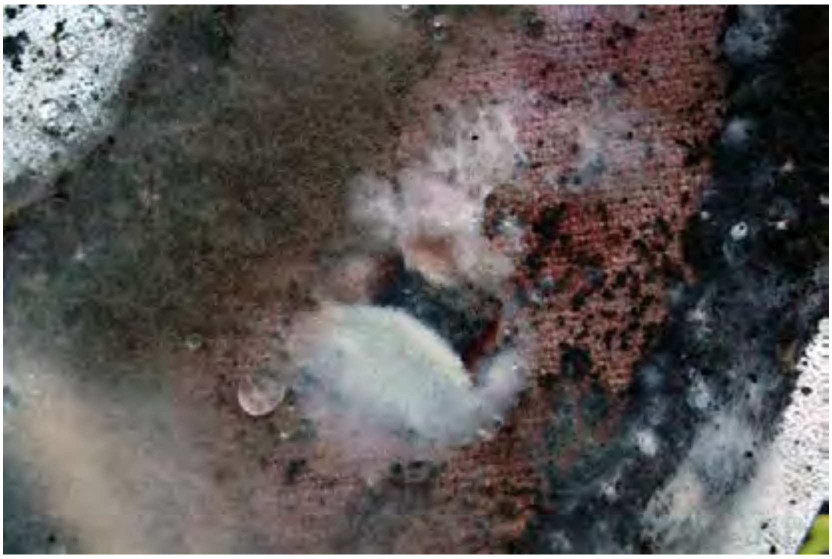

Fig.12

For designers, co-working with living organisms transcends the conventional definitions of the hand-made and the man-made. If as argued by Ingold, practitioners*, "are wanderers, wayfarers, whose skill lies in their ability to find the grain of the world's becoming and to follow its course while bending it to their evolving purpose"* (Ingold 2011, p. 211), then, by co-working with organisms such as mycelium, designers have the opportunity to evolve their purpose and develop alternative sustainable bio-materialities.

3/ Grow-made Textiles

We have a long-established history of cooperation with living organisms. Making wine, baking bread and maturing cheese are all evidence of a historical sustained ability to exploit the living qualities of yeast to make food. For designers, controlling the morphogenesis of living materials enables a new form of expanded design practice. However, *"not all aspects associated with life are welcome in technology. In our human-made systems, we strive for predictability, controlled processes and defined outcomes"* (Imhof, Gruber, 2016, p. 22). How can we then incorporate living dynamic qualities into our production systems? One option is to design fully controlled environments of growth to alleviate any variables, such as achieved by Ecovative and MycoWorks when mass-manufacturing mycelium packaging materials. The other is perhaps to apply soft control systems such as used in bread making. Fig.13 shows a monitoring board used to record the various ambient parameters in a sourdough specialist bakery in East London.

Fig.13. E5 bakery, East London. Photography Carole Collet

This board is used to compare the baking of bread from one day to the next. As the bread is sold at a fixed price, bakers aim at achieving some form of regularity even though the starter sourdough they work with will respond differently to daily changes in ambient temperatures. The monitoring board records the room, water, and flour temperature. On the left is the name of the different breads: MG stands for Multi Grain, HW is for Hackney Wild and so on. This board enables bakers to fine-tune their recipes in accordance with the results of the previous day. This picture was taken early on a Friday morning so the Friday column is still empty. Although the bakery does not operate within a fully controlled environment, by monitoring the day to day variables bakers can adapt the recipes and manage to produce loaves of bread that are consistently regular in forms and taste. This strategy is a means to address issues of control and predictability when manufacturing with living organisms.

So the integration of biology into material systems is both a historical practice as seen with baking, and a contemporary sustainable form of production as implemented by companies such as Ecovative and MycoWorks. In both models, the developmental morphogenesis of a material can become a site for design intervention. This requires a new approach to design and a need to revisit our understanding of creating forms. From an anthropological perspective, the process of co-designing with a natural organism resonates with Deleuze and Guattari's argument that *"the essential relation, in a world of life, is not between matter and form but between material and forces"* (quoted by Ingold, 2011, p. 210). As seen in the section above, developing mycelium textiles is the result of a tension between dynamic living forces, environmental parameters and materials. By encouraging metabolic functions or preventing them, grow-made protocols contribute to intersecting new material agencies.

This approach seems to challenge the unbalanced hierarchy between form and matter inherent to Aristotle's holomorphic model.

> *To create anything, Aristotle reasoned, you have to bring together form (morphe) and matter (hyle). In the subsequent history of Western thought, this hylomorphic model of creation became ever more deeply embedded. But it also became increasingly unbalanced. Form came to be seen as imposed by an agent with a particular design in mind, while matter thus rendered passive and inert, became that which was imposed upon'* (Ingold 2011, p. 210).

Co-working with living organisms allows us to incorporate active and dynamic qualities to matter, which is not rendered 'victim' of a shape-forming activity, but rather becomes the enabler of the morphogenetic process. *"Organisms are bundles of relationships that maintain themselves by adjusting their own behaviour in anticipation of changes to the patterns of activity all around them"* (Weinstock, 2010, p. 22). Understanding these behaviours is the main concern in engaging with grow-made materials. Designers will have traditionally learnt how to master hand-made techniques to shape materials, and they will have explored a range of manufacturing processes to control and exploit the properties of man-made materials. They are used to working with a material once it is grown, or killed and harvested (such as cotton) or once it is man-made (such as polyester). With grow-made textiles the hierarchy between matter and form is transformed into a symbiotic and evolving relationship. In 1917 scientist Wentworth D'Arcy Thompson argued that a form, living or not, is the result from the *'diagram of forces'* that have acted upon it. We can argue then that to grow-make a textile, designers have to understand and harness the forces that can influence the dynamic properties of life. This is a new paradigm both for the design discipline and for the textile industry. We can grow new biodegradable materials such as the self-patterned mycelium rubber above, or the mycelium leather launched by MycoWorks in September 2016. But we can also begin to explore how to grow finishing and coating processes that can replace polymer-based techniques such as pigment printing. We can use mycelium to repair and mend cloth, or to give it structural properties, and we can fine-tune a range of biodegradable coatings grown at ambient temperature. This is still very early on, but the potential of grow-made mycelium textiles can propose a new set of options for sustainable textiles, fit for the circular economy.

Conclusion

This paper discusses the emerging paradigm of the 'grow-made' arising from new practices in biodesign. Using a design research project 'Mycelium Textiles' as a focus to unravel the potential of developing alternative sustainable design and textile production models, the paper starts by positioning biodesign practices within a hierarchical framework. Going beyond biomimicry and the emulation of natural systems, the paper showcases how strategies for co-working with a living organism such as mycelium can lead to evolving a new bio-materiality that incorporates the advantages of biological fabrication. To fully explore the potential of biofacturing, designers need to expand their practice and incorporate a new skillset that enables them to nurture and control the behaviours of living organisms. Whilst the development of new materials has predominantly been the remits of engineers and material scientists, designers are now expanding their roles from shaping existing materials, to creating and growing new ones. Designers can now navigate the hand-made, the man-made and the grow-made to imagine sustainable alternative propositions for the future. As the 'Mycelium Textiles' project continues, the next step will be to grow a range of finished textile and fashion accessories that fully exploit the potential of slow-grown embellishments with mycelium colonization techniques.

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Carole Collet has dedicated her career to developing a new vision for design, and pioneered the discipline of Textile Futures at Central Saint Martins in 2000. She is now Professor in Design for Sustainable Futures and Director of the Design & Living Systems Lab at Central Saint Martins, University of the Arts. Her research focuses on exploring the intersection of biology and design to develop speculative and disruptive sustainable design proposals. Collet's ambition is to elevate the status of design to become a powerful tool that contributes to developing innovative paths to achieve the 'one planet lifestyle'. Her recent curation of '*Alive, New Design Frontiers*' (www.thisisalive.com) questions the emerging role of the designer when working with living materials and technologies such as synthetic biology, and establishes an original framework for designing with the living via the lens of sustainability. One of Collet's characteristics is that she takes on different research roles, from designer, to curator and educator. This enables her to develop an informed critique of both the design outputs and the design contexts, from making knowledge to framing knowledge. Her work has been featured in international exhibitions and she regularly contributes to conferences on the subject of textile futures, biodesign, biomimicry, synthetic biology, future manufacturing and bio-materiality, sustainable design and climate change.

Interlacing Surfaces:
Relating Tim Ingold’s Understanding of Material to Material in Interface and Interaction Design

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Abstract

Unlike in other fields of design, interface and interaction designers rarely relate an understanding of material to the process and outcome of their work. Their practice seems to be to engage with information rather than material. However, a different perspective has been brought into focus recently: Researchers have started to investigate the material dimension of digital data from a theoretical angle, while new developments in the field of wearables, e-textiles and smart materials focus on the material side of interaction. However, when discussing these approaches, it is still difficult to establish what kind of understanding of material should be applied.

As a contribution to this field of research, we highlight problematic aspects of a dichotomous perspective on the relationship between material and information in relation to computational things. We introduce Ingold’s processual understanding of material, which evolves around the critique of this specific dichotomy. Then, Ingold’s understanding is discussed in comparison with exemplary approaches from design, digital humanities and computer science. Through this comparison unresolved aspects of the implied material-information relationship become apparent.

In the second half of the paper an exploratory method based on material samples and performative observation has been chosen to investigate this relationship further. As a result, three categories are drafted that are understood as a basis of a processual understanding of material in interaction and interface design.

In the overall context of the conference, this contribution adds a perspective to designing with materials by exploring a processual understanding of material in relation to information.

Keywords

understanding of material; material-information dichotomy; processual understanding; Tim Ingold; interactive surfaces

A common assumption is that a designer’s, artist’s or architect’s understanding of material strongly influences their work (Ashby & Johnson, 2010; Lange-Berndt, 2015; Menges, 2015), but this seems not to apply to the field of interface or interaction design. One view appears to be that interaction designers engage with information rather than material, or with something intangible such as “material without qualities” (Löwgren & Stolterman, 2004, p. 3). However, the very material dimension of computer-based processes has been brought into focus from diverse perspectives over the last decade (by, amongst others, Kirschenbaum 2008; Vallgårda & Redström, 2007; and Wiberg 2014). At the same time, it is not surprising that researchers are starting to investigate the material dimension of computing at a time when the standard plastic cases are being peeled from personal computers as they become embedded into “everyday computational things” (Redström, 2001, p. 1). Different researchers have already put forward differing terms to understand, describe and make use of this specific material situation. In this paper, we aim to make the following contributions within this context:

- We relate Ingold’s understanding of material – based on the critique of a dichotomous view of material and information – to exemplary approaches from design, digital humanities and computer science. We reveal that these approaches imply but do not specify a material-information relationship within their concepts.
- To reveal the underlying material-information relationship an explorative method is applied. Material samples of the concept of *interlacing surfaces* are observed through motion blur photographs.
- Through this observation potential categories of a processual understanding of material are drafted. In conclusion, a processual understanding of material is proposed for the field of interface and interaction design.

The research presented is part of a doctoral research project and therefore in a state of ongoing progress.

Material and/or Information

As is the case with many dichotomous perspectives, the material-information dichotomy is not easily resolved. Within an extended discussion, there is a long and complex historic background to both terms and their relationship (Wagner 2015). With the focus on computational things, the material-information discourse surfaces from the 1980s onwards, within which a dichotomous view of material and information seems to be deeply embedded.

With the advent of the personal computer and its increasing networked connectivity, the immaterial quality of information has been strongly brought into focus. Digitally encoded data are described as existing autonomously from their material manifestation. Being able to copy and transmit information without noise or loss prompted Negroponte to predict: “The change from atoms to bits is irrevocable and unstoppable” (1995, p. 4). Negroponte depicts the “bit” as the smallest unit of information detached from physical qualities. An earlier example positioning the new technological achievements detached from material conditions is the exhibition *Les Immateriaux,* curated by Lyotard in 1985. The visitors were invited to explore exhibits of new technological achievements such as artificial skin, new telecommunication devices, projections and holograms. The stated objective was to “sensitize” the audience for the new “immaterials” that would alter the relationship between humans and matter (Lyotard, Chaput, Burkhardt, & Maheu, 1984, p. 2). While Negroponte promotes the complete detachment of information from matter, Lyotard et al. stress how new technologies render material processes imperceptible for the human observer. Both concepts – the “immateriality of digital media” and “bits over atoms” – partially remain at the center of the understanding of computation today.

An opposing view only started to form at the end of the 20th century, investigating the material side of computation (Wiberg et al., 2013). Kirschenbaum was one of the first to devote sole attention to the material state of storage – mainly the hard drive – within computation. While arguing from a forensic perspective, he closely examines the very material traces of digital data. Kirschenbaum subsequently distinguishes between *forensic* and *formal material* (Kirschenbaum, 2008, pp. 17–23). *Forensic material* is related to physical evidence of inscriptions such as ink, paper or material traces, while *formal material* describes the relationship between these elements established through cultural codes such as the layout of text and images, or a particular style or context.

Although this distinction may resemble our everyday understanding of material, it becomes problematic when it is read as dichotomously separating information and material, since this separation promptly implies that humans encounter a complete yet meaningless material world (*forensic*) into which superordinate (*formal*) information may be inscribed (cf. Hall, 2016, p. 109, Ingold, 2007, p. 3). Ingold opposes this general dichotomous view from an anthropological perspective, highlighting that every inscription is a close interplay between material and form (Ingold, 2013, pp. 24–31). He understands material as being "processual and relational," continuously engaged with form (Ingold, 2007, p. 14).

At this point it is important to establish how information is understood and may be defined in this context. Ingold's perspective is in short revealed through the hyphened spelling "in-formation" (Ingold, 2007, p. 11). This points to the etymological root of the word, "to give form to the mind," as well as to ecological information theory. Within this field, information is understood less as distinct symbols that need to be decodified but as an ever-changing informing environment humans are embedded in (Bateson 1987). With this understanding in mind, it becomes clear how "in-formation" is inseparable from material according to Ingold's perspective.

Since we consider a dichotomous view of material and information as equally problematic within the discussion of computational things, we propose focusing a processual understanding of material based on Ingold's perspective. To investigate the applicability of his understanding for computational things, we compare exemplary approaches from within the field with the focus on this relationship.

Framing a Processual Understanding of Material

In *Materials against Materiality,* Ingold frames his understanding of materials as "the active constituents of a world-in-formation" (Ingold, 2007, p. 11). For him, material and information are not fixed entities opposing each other, but rather indivisibly interwoven in a continuous process. From a crafts perspective, Ingold argues that weaving a basket is a continuous process between the basket maker and the rod. It is not only the maker forming the rod, in-forming it into a basket, but also the properties of the rod forming the maker's moves and informing him (ibid., p. 31). Although Ingold's work cannot be discussed in full depth here, we intend to highlight one concept, namely that of *correspondence*. Ingold uses this term in contrast to interaction: while interaction implies fixed entities or agents exchanging back and forth, in "correspondence, by contrast, points are set in motion to describe lines that wrap around one another like melodies in counterpoint" (Ingold, 2013, p. 107). Based on one of Ingold's inspiring diagrams on this topic, the relationship between material and information may also be imagined as similar (see Fig 1.). While from a dichotomous perspective material and information are positioned as fixed points opposing each other, a processual understanding of material points to an open-ended *correspondence* unfolding through time and space.

To relate Ingold's understanding to the understanding of computational things, the following three approaches from within the field provide valuable indications as to how this concept may already be applied. While none of these authors quote the work of Ingold, they reveal important common assumptions and approaches towards an understanding of material within the field of interface and interaction design. Therefore, it is of high interest to investigate the implied understanding of the material-information relationship of these approaches (see Fig. 2).

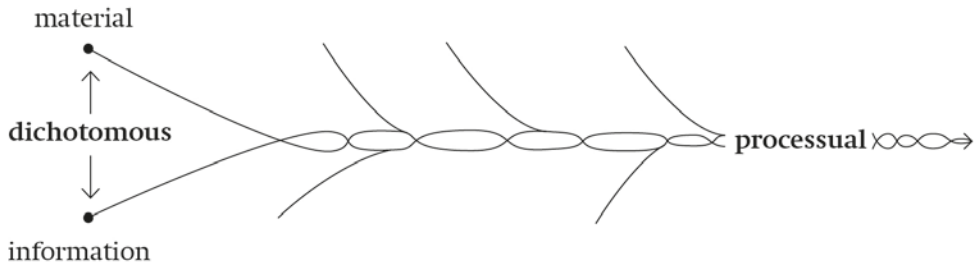

Fig 1. Difference between dichotomous and processual perspective (Inspired by the graphic “Interaction and correspondence;” Ingold, 2013, p. 107)

The first concept “becoming materials” by Bergström et al. (2010) focuses on smart and computational materials from a designer’s perspective. These represent a new field of development of materials with the ability to change properties (e.g. color or shape) repeatedly in correspondence to external stimuli (e.g. temperature or current). Since these changes only unfold within use, the authors stress: "Becoming materials, in contrast, can best be understood and described in terms of change in expression, in context, over time" (ibid., p. 158). This definition matches Ingold’s understanding, implying both temporal and context-relational involvement. Bergström et. al. explicitly ascribe these qualities to smart and computational materials and dissociate these from other material processes such as “patina or disintegration” (ibid., 2010, p. 158). Nevertheless, they also acknowledge the swelling of wood caused by humidity and differing reflections of steel as *becoming* (Bergström et al., 2010, p. 158).

On the one hand, approaching smart materials as being separate from other material processes underlines the relevance of a new material understanding from a technological and design perspective. On the other hand, understanding all materials like wood and steel as becoming is very much in line with Ingold’s argumentation (Ingold, 2007). Here, the interesting question arises of whether the understanding of these new materials might not benefit from integrating them within a broader understanding of material being inherently processual, as Ingold suggests. The material-information relationship underlying the concept of “becoming material” is not explicitly stated, but is implied within the temporal and contextual understanding. This point is of high interest for further investigation.

The second concept to be reviewed is rooted in the field of digital humanities. Drucker proposes her approach in *Performative Materiality and Theoretical Approaches to Interface* (2013). She discusses Kirschenbaum’s understanding of *forensic* and *formal* material and phrases her concept of performative material as a further development from this towards post-structuralist thinking. She disproves an ontological or literal understanding of material that implies certain meaning deriving from the material itself. Therefore, her approach frames the “performative dimension of use” (Drucker, 2013, p. 12).

She focuses on describing software interfaces as performative material and at the same time contributes to a broader argument to re-engage digital humanities with critical theory. By contrast, Hall highlights that her approach might still imply a dichotomous understanding when she distinguishes between literal material and the performative enactment provoked by it: “What is less clear on this basis is whether she considers the performance itself to be material or whether the performance transcends the material” (Hall, 2016, p. 112). Bringing in Ingold’s understanding of a continuous correspondence, one might ask whether material and performance are not just as tightly interwoven as material and information from a processual perspective (see Fig 1.). Again, this question requires further investigation.

The last thread originates from Tone Bratteteig’s book chapter “A Matter of Digital Material” and her introduction of the term ‘processual material’ (2010). Written from a system design and computer science perspective, she considers processes as the "'raw' material of a computer" (ibid., p. 158). Furthermore, she highlights how the notion of understanding computation as immaterial is evoked through the multiple layers of complexity and abstraction involved. These range from the distinction of continuous voltage current in 0s and 1s, all the way to symbolic representation on a screen (c.f. Winograd, 1986). Although one sub-chapter is titled "processual material" (p. 160-161), what Bratteteig describes is not fully congruent with Ingold's understanding of "processual and relational" material. As Bratteteig highlights, processes within computation are always based on linear and causal abstractions. This is why she describes resemblances with performative arts such as music, dance or theater, where formal descriptions unfold in time and space.

Here, she is more in line with Drucker's performative understanding of material imposing the same question, namely whether "processual structures" are only a precondition for "materializing different processes." Bratteteig further refers to Barad's critique of the representational thinking within computer science and introduces Barad's concept of "material-discursive" (Barad, 2007, pp. 132–188). Barad stresses how the concept of an artefact and its material dimension are inseparable. Bratteteig especially sees this as embodied in "new digital materials" such as e-textiles, 3D-printing, tangible user interfaces and virtual worlds (Bratteteig, 2010, p. 165). At this point, again the material-information relationship is only implied, especially with the question of representation, abstraction and layering, whereby it is worth further exploration.

APPROACHES TO A PROCESSUAL UNDERSTANDING OF MATERIAL

– no title specified –	**concept**	**„becoming material“**	**„performative material“**	**„processual material“**
Tim Ingold	*author(s)*	Bergström et. al.	Johanna Drucker	Tone Bratteteig
anthropology	*research field*	design	digital humanities	design & computer science
relationship between making and material	*focus*	altered relationship between design, use and context	performative dimension of use and meaning	representational thinking
crafts	*perspective*	smart materials	software interfaces	computer architecture
inseparably interwoven	*material-information relationship*	–	–	–

a processual understanding of material
in interface and interaction design

Fig 2. Comparing Ingold's approach to approaches from the field of design reveals the missing positions regarding the material-information relationship.

In conclusion, through touching upon these three exemplary approaches and through being aware that there are more to be analyzed (*for example* Döring et al. 2013; Barad 2007), common and differing threads are revealed. The overall aim is to combine these threads to a processual understanding of material. In comparison (see Fig 2.) the missing clarification of the material-information relationship becomes apparent.

The understanding of becoming material by Bergström et al. highlights a strong relevance from a technological and design perspective, engaging with the challenges of new material development.

Here, the material-information relationship might face very new challenges if material itself processes and displays information. Drucker stresses a focus on performative qualities rather than literal meaning. Here, investigating the material-information relationship further might raise new questions for designing with materials. Bratteteig's understanding of processes at the core of computation reinforces the application of the term "processual." At the same time, the causal abstraction of the computer processes introduces new layers of complexity to the material-information problem.

We assume that in exploring these missing clarifications the base for a processual understanding of material within interface and interaction design may be revealed.

Interlacing Surfaces – Exploring a Processual Understanding

> It is this back-and forth or discourse, that provides the testing-ground of new ideas, and which establishes their interest. From the point of view of creative research, materials are always in a state of becoming. (Carter, 2007, p. 19)

This statement by Carter may be equally matched by Schön: "I shall consider designing as a conversation with the materials of a situation" (1983, p. 78). Both challenge the idea of theory and practice as separate working cycles. Equally, Ingold criticizes an overly-theoretical engagement with material ascription without close examination of material realities (Ingold, 2007). In accordance with this position, the second half of this paper is dedicated to the close engagement with material processes exploring the material-information relationship, which has been revealed as missing in the approaches analyzed thus far.

Three material samples of interlacing surfaces are presented to further investigate the material-information relationship. One may think immediately of the screens as the surface through which we usually engage with digital processes. However, while the screen may be understood as a window to another world (Manovich 2002, pp. 95–103), the term 'interlacing surface' is chosen to address the entanglement closely above and beneath this layer.

In our doctoral research project, we hypothesize that engaging with such an understanding through a design process alters the way in which material processes are perceived and transferred to applications. At this state of research, the attention is drawn to gaining insights into the material-information relationship through performative observation of material processes.

Performative Observation

The challenge of documenting material processes in relationship to Ingold's work has been addressed by Knappett (2011), amongst others. The problem that he pinpoints is that there is essentially no method, or rather practice of analyzing, comparing or discussing the processual and relational material world that Ingold describes. Knappett suggests focusing on the anthropological technique named *chaîne opératoire*. This technique is mainly used in an archaeological or ethnological context to describe, for example, the making of a metal axe through a series of discrete working steps. However, Ingold criticizes this technique for reducing processes that are "more like an unbroken, contrapuntal coupling of a gestural dance with a modulation of the material" (2013, p. 26) into fixed separate states.

The method that we will explore at this point is taking series of motion blur photographs. We regard these as an intermediate method between something abstract like flow charts and time-based media such as film. Through time, exposure movement, speed, and space relations are meant to be captured.

Sample 1: Becoming Material

In the first sample, the concept of “becoming material” is explored. Purposely, the material explored is developed with unusual qualities but may not be considered a smart material. The sample comprises a ceramic tile, which is cast with a thin layer of embedded fabric mesh. Therefore, when cracked, the pieces do not fall completely apart but rather stay connected, creating a flexible surface. The transformation thereby occurs through use (cracking the material) and time: in correspondence between hands and material; for example, the leverage of the hands in relation to the strength of the material creates specific breaking lines (see the first row of Fig 3.).

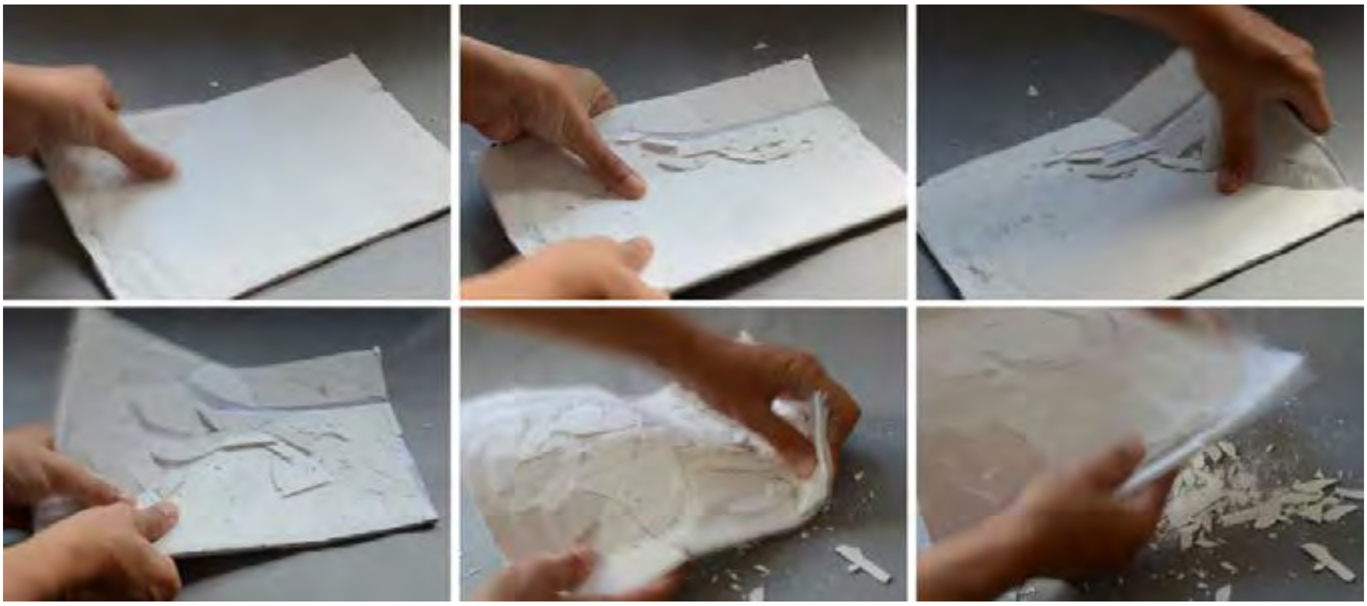

Fig 3. Process of cracking ceramic

The series of motion blur images document the dynamic of the process (Fig 3.). While the surface is mainly intact, the force is applied punctually, creating response only in the cracked part. The more the surface is cracked, the more dynamically it reacts to movement. When comparing the starting point and result of the process, two very different material and informational situations are met. The material and information relationship presents itself as unfolding over time and use.

Sample 2: Performative Material

Fig 4. Correspondence with movement and touch

Through the second sample, the performative quality of material is explored. A sheet of paper is cut in a way that creates protruding triangles. Cutting the paper reveals an interesting shift from the smooth, finished surface of paper to a roughened surface that expands and presents push-back when touched. Bending the sheet results in different, uneven shapes, producing a rustling sound when in motion. Most interesting regarding this sample is its haptic, kinetic and variable quality. When held in hand, it seems to be in constant correspondence with movement and touch (Fig 4.).

The depicted series reveals the three-dimensional shapes created in motion. Through the motion blur, their instability and dynamic are exposed. Unlike the series of the previous sample, the process does not have a start and end result, but rather it documents the temporal and spatial quality of the sample, which can only be explored when held in hand. The performative quality described by Drucker is depicted in its instability and constant interplay between material and information, making and using.

Sample 3: Processual Material

The two previous samples focus on the correspondence between hand and material. This may be regarded as a first layer of in-forming, although – as Bratteteig highlights – when designing for interactive systems we are confronted with multiple interlacing layers of information and abstraction (2010). To expand exploration in this direction, projection on the surface is used to integrate an additional layer of information. This step is inspired by the projects FoldMe (Khalilbeigi, Lissermann, Kleine, & Steimle, 2012), PaperFold (Gomes & Vertegaal, 2015) and Paddle (Ramakers, Schöning, & Luyten, 2014), each of which investigates the possible interaction with foldable, hand-held screen devices. While these projects present very interesting forms of interaction, they mainly use material as a passive projection surface. From a processual understanding and within the concept of interlacing surfaces, it is tempting to question whether the material might not actively interact with the information presented.

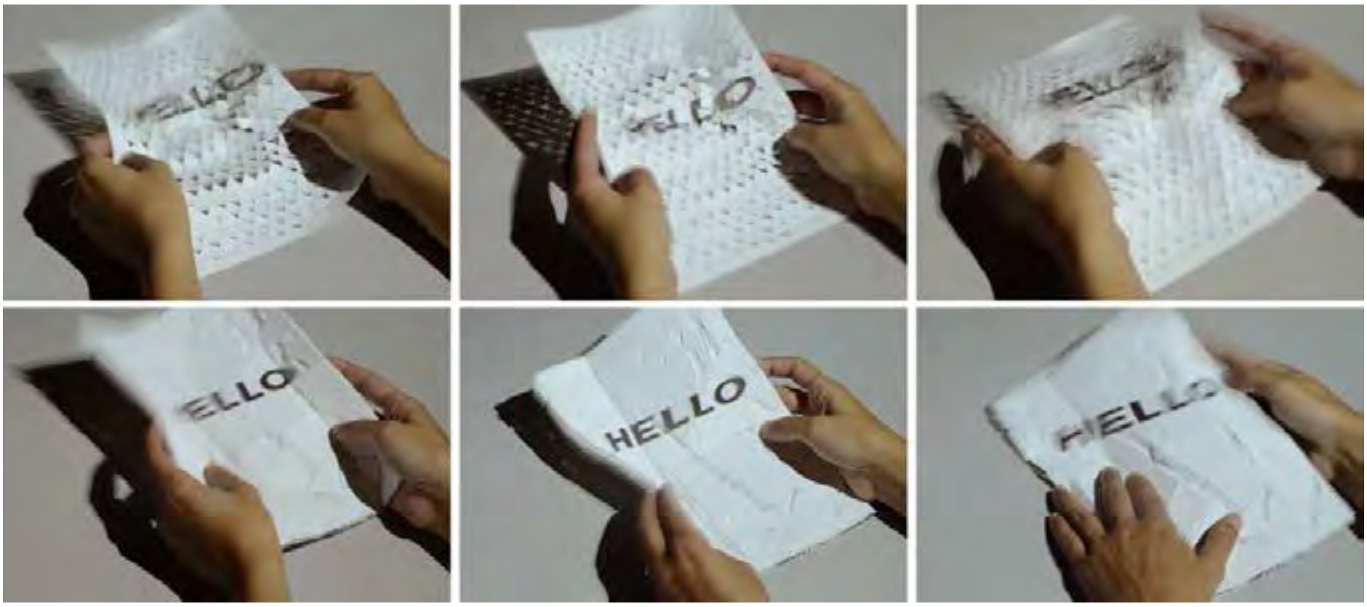

Fig 5. Testing projection as a second layer of information

At this stage, the correspondence between hands, material and projected letters reveals how the properties of each layer influence the other (Fig 5.): different gestural movement translate into the material behavior and distort the letters, provoking new figurations. In close correspondence with Drucker's approach, this interplay is enacted through use.

A Processual Understanding of Material in Interface and Interaction Design

Through the research conducted, the underlying material-information relationship of the three approaches is explored. In the following these are understood as potential categories of the processual understanding of material. All three relate to Ingold's understanding of material and information being inseparably interwoven.

Material and Information – Corresponding over Time

The concept of becoming material stresses the temporal, contextual quality of processes. As depicted in the first sample, time, material and information are closely related. The method of observation only presents a reduced clipping of this ongoing, open-ended process, which can be traced further in both directions. This is an important aspect for the field of interface and interaction design, since the things to be designed are always time- and context-based. This understanding has been framed as “temporal form” (Redström 2001). Ingold’s perspective adds the understanding of ongoing relational correspondence to this.

Material Provokes Information Provokes Material

The ongoing, back-and-forth between material, making and use is key to understanding performative material. This is equally matched in a continuous, back-and-forth between material and information. When holding the second sample, the material changes, which changes the way in which the sample is moved. It is not only the material provoking performance, but also the performance provoking the material. Therefore, performance and material present themselves – in this case – as being processual and related, much like material and information in correspondence (Fig 1.).

Material and Information – Interlacing Layers

Understanding material and information as interlacing layers proposes another view on the material-information relationship. In the third probe, this becomes apparent, when the projected letters are clearly distinguishable in some images, while in others it seems to blur with the material (Fig 5.). It seems to be important to understand this relation as being constantly in flux. This might reveal how material and information seem so clearly separable to the observer at one time, while in the next moment they seem indistinguishable. Here, new questions arise concerning how material layers might relate to information layers, such as in the concept of “computational composites” (Vallgårda & Redström, 2007).

Conclusion

In this paper, three main steps are presented, which form the groundwork for an ongoing doctoral research project. First, the problem of a dichotomous perspective on the material-information relationship is revealed and Ingold’s critique and differing understanding of material is discussed. In relation to similar approaches from the field of design, digital humanities and the computer sciences, it becomes apparent that an explicit positioning towards the material-information relationship is missing within these approaches. Based on this premise, the preliminary research in the field of interlacing surfaces explores the possible underlying concepts of the material-information relationship through three samples. Finally, the depicted research is interpreted in three categories that may influence the understanding of a material-information relationship within interaction and interface design.

While this is only a first step towards exploring the complex interplay between material and information, further research aims may be formulated: first, investigation needs to be continued regarding how the material-information relationship is formed. Here, more radical forms of interplay need to be sought to test the proposed categories. The incorporation of smart materials and “computational composites” offers the next steps of complexity to be explored.

In the context of the theme of the conference, Ingold's understanding of materials as being always alive, active and adaptive adds a new perspective to the design with materials:

> Bringing things to life, then, is a matter not of adding to them a sprinkling of agency but of restoring them to the generative fluxes of the world of materials in which they came into being and continue to subsist. (Ingold, 2007, p. 12)

From this perspective, in this paper we have pinpointed an approach to continuously engage with material processes within the field of interface and interactive design, with the potential to bring forth novel aesthetic and interactive qualities.

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‘Experience Prototyping’ Smart Material Composites

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Abstract

This paper presents the concept and development of a real-time hybrid tool to support the designers in experience prototyping of an underdeveloped smart material composite. In a EU project, Light-Touch-Matters, designers have been asked to explore the potential of composites of OLED technology and Piezoelectric polymer, that are assumed to revolutionize the ways we interact with our surrounding products. However, these technologies are not yet at the stage for designers to be investigated directly and/or implemented across different projects. To realize the potential of the material development, it is essential for designers to understand how these developing composites and their attributes might be experienced. Elaborating the gap in capturing and prototyping the performative and dynamic qualities of these composites across five design cases, we propose a material-driven approach complemented by generative Chroma keying tools to fill in this gap. Testing an initial post-processed Chroma keying technique with a group of designers, we further developed a real-time hybrid simulator, which we present in the last section of this paper.

Keywords

Experience prototyping; smart materials; experiential qualities; Chroma Key; video editing; design tools

New compositions of smart materials are being conceptualized and developed that allow for flexible, soft and more integrated interactive products (Nathan et al, 2012; McEvoy & Correll, 2015). Many of these composites are still in early development and not mature enough to be used in real-life products. However, there are initiatives to involve designers in exploring and communicating the unique design possibilities of these underdeveloped composites and influence their development (see projects e.g. Light-Touch-Matters, http://www.light-touch-matters-project.eu/; Solar-Design, http://www.solar-design.eu/). It is supposed that smart material composites can partake in product’s embodiment as well as its temporal content (similar to user interfaces). Hence, they will dramatically change the appearance and experience of interactive products. In order for designers to conceptualize and represent meaningful applications, i.e., applications that exploit these technologies to create appropriate and new experiences, they need to understand, explore, and communicate the experiential aspects of these underdeveloped composite.

The vocabulary and schematic representations used by engineers and scientists to communicate the physical and technical performances of these underdeveloped composites hardly represent their experiential qualities. Experiential qualities of materials concern the qualities that are not inherent to materials but elicited by them in human-material interactions (Karana, 2009). These qualities include sensorial (e.g., soft), interpretive (e.g., modest), affective (e.g., surprising) descriptors as well as actions (e.g., caressing) evoked by materials (Giaccardi and Karana, 2015). To compensate for such knowledge gap, designers use substituting technologies and techniques to approximate the materials experience, e.g., through *prototyping* (Barati et al., 2015a; Barati et al., 2015b). Prototyping refers to the designer's activities to create representations of a design before final products exist. "Experience prototyping", a notion first used by Buchenau and Suri (2000), spares out the activities and tools used by designers in supporting their (or users' and clients') understanding of the important aspects of the real user experience.

The attitude of designers to create early representations of their ideas and understandings can be very useful in collaborative material development in which multiple stakeholders are involved, including material scientists, engineers and design researchers. By externalizing designer's understandings and exposing them in a rather stable and tangible format, prototypes give the development team a chance to establish shared understandings about specific aspects of a design and the objectives. Particularly in early stages of the development process, when many aspects of the design are either unknown and unspecified, these external representations are useful in defining and negotiating the boundaries (Lee, 2007). To make sure that the experiential qualities, unique to these underdeveloped composites, receive adequate attention in the early discussions about the development direction and boundary definitions, *experience prototyping* them becomes an important quest.

In this paper, we present our approach and the tools, developed to support understanding, exploring and communicating the experiential qualities of a specific group of smart material composites. Light-Touch-Matters, or LTM materials (Fig 1), are thin and flexible composites of OLED and Piezoelectric polymer. Their development is part of a broader technological shift towards tightly integrated composites of sensing and actuating materials and technologies, and computation (c.f., McEvoy & Correll, 2015). In a EU project, material scientists and designers have joined forces to co-develop these composites and show case innovative applications (www.light-touch-matters-project.eu). Our previous studies of the design strategies and prototyping tools, used in designing with the LTM materials suggest a gap in capturing and exploiting the dynamic and performative qualities of these materials (Barati et al., 2015a; Barati et al., 2015b). In this paper, we elaborate on this gap and take the first steps towards supporting the designers in better understanding of the overlooked design space.

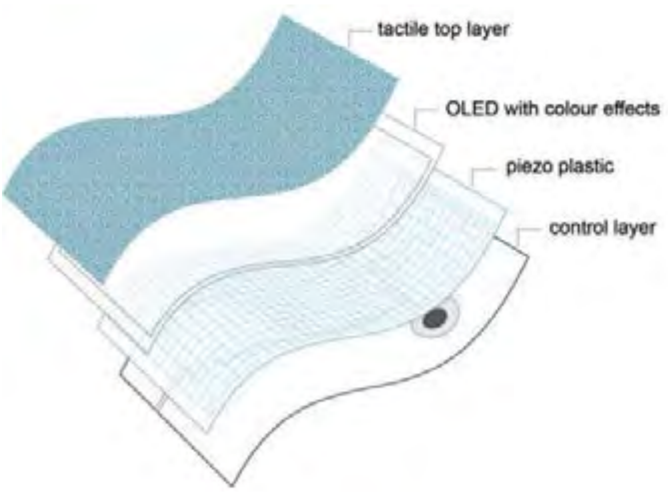

Fig 1. A schematic representing the components of the LTM materials. Ref: www.light-touch-matters-project.eu

Materials Experience

'Materials experience' as a notion was first introduced by Karana (2009), to acknowledge the active role of materials in conditioning and influencing our experiences with and through materials. Materials experience has been recently extended to also consider the active role of materials in shaping our practices (i.e., ways of doing) around artifacts (Giaccardi and Karana, 2015). Accordingly, Giaccardi and Karana (2015) argue that materials can be experienced at four experiential levels, (1) sensorial: how the material is received through the five senses (e.g., hard, transparent), (2) affective: the emotions elicited in interaction with material (e.g., surprising), (3) interpretive: the meanings assigned to the material (e.g., cheap-looking), and (4) performative: the actions involved in handling the material (e.g., pressing, knocking). A comprehensive understanding of these experiential qualities paves the way towards conceptualizing meaningful material applications (Karana et al, 2015).

Prototyping Materials Experience

Buchenau and Suri (2000) coined the term "experience prototyping", where prototyping aims at getting a sense of the real experiences and letting the designer reflect upon them. *Experience prototyping* has been used to facilitate different activities during the design process, including understanding, exploiting and communication the experiential aspects of designing and using not-yet-exiting artifacts. Note that any attempt in capturing the experiences, before the object exists, is inevitably an approximation and partial simulations of the real experiences (ibid). The tools and techniques used for *experience prototyping* are aligned with the attitude of "exploring by doing" and 'actively experiencing the sometimes subtle differences between various design solutions' (ibid).

While *experience prototyping* as a practice has been encouraged in the process of designing interactive systems, there are evidences of its relevance in exploring and communicating the qualities of materials (e.g., Saakes, 2010). For an underdeveloped smart material composite, *experience prototyping* provides ways of testing assumptions and forming new assumptions, about the look and feel of the composite and the changes over the course of interaction.

The LTM Materials: 'Underdeveloped' Smart Material Composites

Being 'underdeveloped' smart material composites, the understanding of the LTM materials experience can be hardly obtained from an in-situ analysis of their experiential qualities (Giaccardi and Karana, 2015). Prior to such in-situ analysis, the LTM materials must be embodied, for which designers require practical knowledge of how to shape aesthetic interactions with such underdeveloped composites (Lim et al., 2009). Referring to the properties and sensing/actuating functionalities of these composites in abstraction, designers may assume the experiential qualities of not-yet embodied applications in their mind and talk about them as if they exist. To that aim, they may use words, sketching tools and prototyping skills to think about the experiential qualities as well as communicate them to other stakeholders. Designers' *priori* knowledge (i.e., knowledge that is known independently of experience, usually by reason) might be deduced from various sources, including the information provided by material scientists and/or existing material/technology cases. Nevertheless, for embodying aesthetic interactions with LTM materials in a concrete way, an understanding of 'what can be done' with these to-be-developed composites and 'how' is critical (Lim et al., 2009).

To understand the possible expressions of LTM materials, as computational objects (see, Hallnäs and Redström, 2002), and support our priori knowledge of their experiential qualities, we frame the LTM materials, as 'thin and flexible material structures that emit lights and deforms over time'. This way, we are able to analyze the experiential qualities of the LTM materials in terms of the constituent interactions between the three elements of *material structure*, *light*, and *time*. Using these elements and their relations, we further analyze the gap in *experience prototyping* the LTM materials and take practical steps towards bridging the gap.

The Material Element

One key element of the LTM materials is the composite structure. The importance of physical embodiment, as an entry point for investigating the expressions of computational objects, has been pointed out in interaction design literature (e.g., Mazé & Redström, 2005; Jong and Stolterman, 2012). As an underdeveloped composite, the formal/spatial relations between different material components are not yet specified. On the one hand, this gives a considerable degree of freedom in form-giving the LTM materials to achieve variety of aesthetic and performative qualities. On the other hand, the proposed components and production methods may suggest certain structures and shapes as more applicable than others.

The Light Element

Light is another important element that becomes an integrated part of the LTM materials experiences. Light as an experiential element has been discussed across various disciplines, such as theatrical design and more recently textile and interaction design (e.g., Janson, 2015, Franinović and Franzke, 2015). In lighting design, photography and theatrical design, the qualities of light are mainly discussed in relation to the effect of light on the objects placed in a light field, including its function (e.g., to see, to convey information) and controllable qualities (e.g., color, intensity, movement). The use of light-emitting technologies, such as LEDs in display technologies and products (not necessarily lamps) stages the light source and its qualities in direct interaction (rather than its effect on other objects). For instance, we may talk about light form, as the light element integrates in a surface. Three basic light forms can be imagined: point (e.g., LEDs), line (e.g., electroluminescent wire, optical fibers), and surface (e.g., electroluminescent paints). Integration of light into textiles and other flexible substrates expands the application and experiential qualities of these composites, particularly, at performative level.

The Time Element

Time plays a crucial role in revealing the experiential qualities of smart and computational materials (Hallnäs and Redström, 2002; Redström, 2005; Vallgårda, 2014; Vallgårda et al., 2015). The computational properties (e.g., sensing, processing, responding) and dynamic behavior of the smart material can only unfold over time as performances develop and reoccur. Even though time has been always a factor in product use, the vocabulary and expressions used to capture the experiential qualities of materials are often considered as static. It is not until recently that design researchers have attempted to theorize *temporal form* as an important design element in form-giving computational objects (Redström, 2005; Vallgårda et al., 2015). Temporal form is defined as “the computational structure that enables and demands a temporal expression in the resulting design” (Vallgårda et al., 2015, p.1). Thus, as an additional layer to a physical embodiment, computational composites require a plan for how events (e.g., different material states) should unfold over time and expressions change one after the other.

Design Explorations 1: Prototyping In-between Each Two Elements

To investigate how designers might have explored the relationships between these three elements, we looked at the external representations, developed and used during five design projects. Four groups of Master’s design students and one individual (as a graduation project) worked on developing product concepts for the LTM materials in six months. The four cases used for this case study are discussed extensively in our previous publications (Barati et al., 2015a; Barati et al., 2015b). We added a fifth case to our analysis to extend the range of tools used not only across multiple application concepts but also in different design phases (i.e., concept design, embodiment design). The fifth case is accordingly an embodiment design of one of the proposed concepts, an interactive Yoga mat, presented in Barati et al. (2015a). All five cases offer interesting instances of *experience prototyping* the physical and temporal forms of the LTM materials.

In the following section, we present a number of representations, used in exploring and/or communicating the experiential aspects of LTM materials at the intersections of the three elements (Fig 2). The first category, 'luminescent material', focuses on the experiential aspects emerging from a physical integration of light and material structure. The second category, 'performable structure', considers the experiential aspects emerging from the changes in material structure over time. The third category, 'dynamic light', presents the tools and representations focusing on the changes in the dynamics, rhythm and speed of light over time.

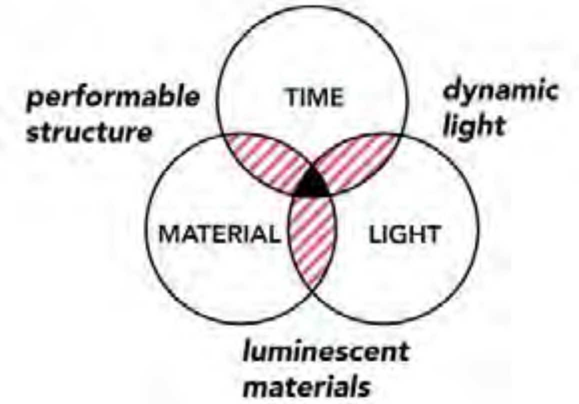

Fig 2. The three elements to capture the physical and temporal forms of the LTM materials and the three prototyping scopes to explore the relationships between each two elements.

Material-Light Relation: Luminescent Materials

The design students used variety of approaches and techniques to consider for relations between the material structure and light elements. While in the early explorations, the two elements were not often co-located in a single unit, the final prototypes aimed at realizing the experiences of both as an integrated part (Fig 4). Fig 3 shows two ways of creating a surface-lighting composite by using LEDs. The actual fabrication of these composites are implemented towards the final stages of concept design and embodiment design (Fig 5). These detailed representations reveal that the designers invested in *experience prototyping* light in a surface form, which could not be simply achieved using point light sources (e.g., LEDs).

Nevertheless, integrating too many LEDs (as hard electronic components) to simulate a surface light resulted in stiffer material structures which was a hindrance for exploring sensorial and performative qualities to their full extent. These sensory trade-offs, in favor of representing higher fidelity visual qualities in prototyping, are quite common in design. However, in experience prototyping the LTM materials, the tactile and performative qualities can be equally important to enable the appropriate performances.

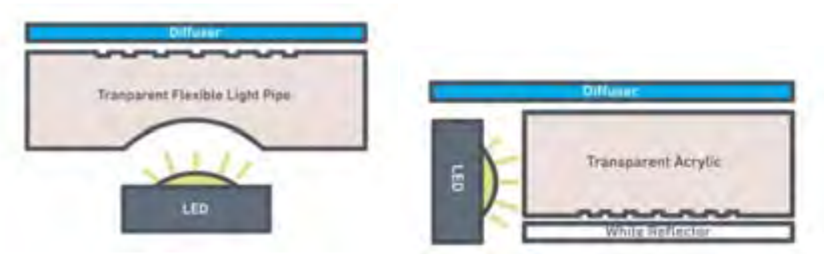

Fig 3. Two ways of making thin and flexible light-emitting surfaces with LED strips.

Fig 4. Using LED strips and multiple layers of translucent fabric as a diffuser.

Fig 5. LED edge lighting allows for a thinner structure in comparison to using top diffusers.

Material-Time Relation: Performable Structures

Structural movement offers a way of looking at the LTM materials as under-specified structures that require pressure and deformation to activate. A ‘performable structure’ is a relationship between the parts of the composite that enables certain *dynamic movements* (Niedderer, 2012) and encourages certain performances with and through the composite. An example of material structures that exploit the dynamic movement of sheet materials is action origami (i.e., a folded structure that can be animated). In order to achieve richer ways of interacting with the objects made of the LTM materials (in comparison to 2D touch screens), the performative aspect of the material structures becomes a central concern in designing with them.

In the cases, we notice only a few instances, particularly in the early stages of ideation and design explorations, that material structures were made and used to represent the performative qualities of the LTM materials (Fig 6). We suspect that the urge to valorize the LTM materials early on, mainly based on the sensing/light-giving functions left limited room for creative material and form explorations. Even though the concepts made use of thinness and flexibility of the composite as “given” characteristics, for instance, to embody a ‘role-able’ Yoga mat or a ‘wearable’ jacket (see

Anonymized; *Anonymized*), the possibilities emerging from an under-specified structure hardly received any attention, proportional to the role of composite structure in characterizing the temporal form.

Fig 6. Physical probes made out of various sheet materials.

Time- Light Relation: Dynamic Light

The interaction between time and light can also point at different experiential aspects. Examples range from dynamics and rhythm of an expressive LED-optical fiber composition (Janson, 2015) to the dynamics of daylight in buildings (Köster, 2004). In our case, the designers have used variety of tools and techniques to explore and represent the experiential qualities of dynamic light. In the early stages of design, the students used *Wizard of Oz* techniques and adjectives (e.g., pulsating, flashing) to characterize and represent the dynamic behavior of light (Barati et al., 2015a; Barati et al., 2015b). In the latest stages of concept specification, they used higher fidelity representations of the dynamic light, e.g., using animated and interactive illustrations on computer screen and light projection on physical surfaces (Fig 7). Programing skills play a crucial role in prototyping dynamic light behavior and diversifying the design solutions. A more sophisticated light behavior was prototyped in connection to the concept functionalities, thus after the decisions concerning the application and vision were made.

Fig 7. left: Interactive simulation of a light-emitting Yoga mat concept, right: the dynamic light is projected on the mat surface.

Design Explorations 2: Understanding The Experiential Qualities of a Unified Physical and Temporal Form

The exploration not only confirmed that the inter-relations between the elements have been of concern in *experience prototyping* the LTM materials, but also pointed at the gap in representing the dynamic and performative qualities of LTM materials, where the three elements overlap (the black spot in Fig 2). The electronic-based approach, for instance using LED pixels, even though is more straight forward when it comes to handling and programing, do not capture thinness and surface light quality, as one might sense in interaction with flexible OLEDs. Our next step, towards understanding the experiential qualities of a unified physical and temporal form is through: (1) making a high fidelity representation, and (2) developing a generative support tool to support early design explorations. To achieve (1), we incorporate a material-driven approach and processed electroluminescent (EL) materials in our university lab. Similar design approaches that start from hands-on processes of a specific material include Jordan et al. (2015), Karana et al. (2015); and Franinović and Franzke (2015).

(1) Electroluminescent Material Demonstrators

Electroluminescent (EL) materials in the form of thin-film displays are available off-the-shelf and have been used in various commercial products, e.g., as backlight for watches. EL materials are also used by artists and designers in creating exclusive light applications and crafts (e.g., “Butterfly Nightlights” by Soner Ozenc and John Wischhusen). Recently, researchers have proposed that EL materials are suitable for prototyping thin-film custom-printed displays (Olberding et al, 2014). Unlike OLED’s complex fabrication which require high-end lab equipment, the chemical inks for making EL materials can be easily processed, using screen-printing method. Screen-printing electroluminescent materials gives more 2D and 3D design freedom to design custom-made demonstrators, compared to off-the-shelf EL displays.

Towards a better understanding of the experiential aspects of the LTM materials in a single smart material demonstrator (Barati et al., 2016), we fabricated EL materials on a thin and flexible substrate (Fig 8). For screen printing, we used off-the-shelf equipment and followed a standard multi-layer screen-printing process. Similar experimental approaches with EL materials have been reported by Franinović and Franzke (2015) and Olberding et al. (2014). The prototyping technique results in higher fidelity representations of the surface light and tactile feel of the OLED component.

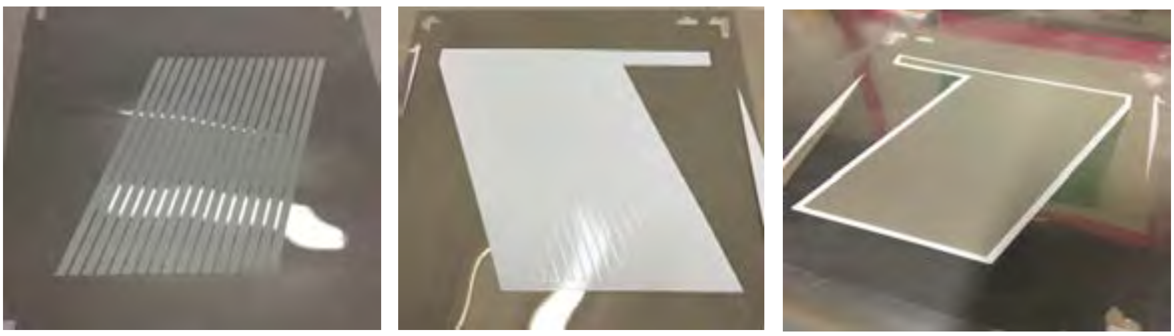

Fig 8. Printing EL on Indium Tin Oxide (ITO) coated PET (the coating makes the surface conductive).

Secondly, we applied Kirigami, i.e., paper cutting techniques, to shape the flat substrate into a 3D structure that enabled a broader, more sophisticated range of actions (e.g., rotating hands in opposite directions), and expressions (Fig 9). Finally, to relate the structural performances to the dynamic behavior of light, a light sensor was incorporated in the demonstrator. The deformation of the structure from fully close to open changes the amount of light received by the light sensor. Hacking a standard DC to AC driver used for EL wires, the intensity of light was mapped to the analogue input from the light sensor (Fig 10). The eventual smart material demonstrator allows to experience the aesthetic and performative qualities of a thin luminescent material as it actively elicits certain performances, influenced by the concurrent changes in light behavior and structural deformation. A video of the demonstrator and how it was made can be found in www.instructables.com/id/Interactive-Electroluminescent-EL-Device-TFCD/.

Fig 9. A Kirigami technique to shape the printed EL sheet.

Fig 10. Adding a light sensor to enable a dimming effect corresponding to structural deformation.

By creating demonstrators made of EL materials, we could firstly understand and explore form, action, expression possibilities in direct conversation with a smart material. Secondly, we could generate high-fidelity EL demonstrators (for more information see Barati et al., 2016). With the knowhow generated during the process of making and the resulting demonstrator, we have substantiated our arguments about the overlooked material experiences offered by the LTM materials. The demonstrator allows the development team to experience and discuss the dynamic and performative qualities of the LTM materials.

On the other hand, even though the created demonstrators raise awareness among the development team about certain experiential qualities, they are not actively enabling further explorations in the overlooked design space. To support further explorations, we suggest a supplementary generative tool that facilitates the adaptation of our material-driven understanding in early stages of the design process.

(2) Chroma Keying: Fusing Dynamic Light in Performable Structures

Our criterion in choosing a technique for generative *experience prototyping* was to accommodate for concurrent structural deformation and dynamic surface light with minimum means. Various methods, including augmented reality and spatial augmented reality (i.e., augmentation of the real world through the addition of digital graphics onto physical objects) exist that allow for fusion of physical structure and digital surface augmentations. Applications of these methods range from product customization (e.g., *Vizera*, www.vizeralabs.com), collaborative development (e.g., *Sparks* platform, www.spark-project.net), and education (e.g., *Shaping Watersheds*, Reed et al., 2014). While most of these methods require sophisticated algorithms and high-end tracking devices to contour the physical object and track the changes, Chroma keying offers a much simpler solution for simulating performable light-emitting surfaces.

Chroma keying, is a special effect for layering two images or video streams together based on color hues. The technique has been used heavily in news-casting, movie-making and videogame industries to create a simulated world for the user. It allows to bring about realistic illusion of alternative conditions, without actually being engaged in them. Application of Chroma keying in simulating the behavior and operation of real-world system over time is chiefly to extract a physical object from its Chroma-keyed environments and place it within a virtual environment (e.g., Coles et al, 2011). The technique, however, can be used to augment different areas of the mock-up while it moves or deforms. This way, an on-screen prototype is created for quick initial sketching of temporal forms.

Post process Chroma keying

As an initial attempt, we have applied Chroma Keying to edit the recorded videos of a deforming structure and add a layer of dynamic light, using Adobe After Effects®. Fig 11 shows screenshots of a video in which a physical material gradually emits surface light as being pressed. Using Chroma key technique, the physical mockup can be made from any kind of tinkering material as long as its color is distinct from its background. Each area of the mockup that is meant to have an individual dynamic light must be coded with a different color. The hybrid of physical structures and digital light behavior allows for simulating the performative qualities of the LTM materials early on, without investing too much time in fabricating EL or LED composites and programing interactive light behavior. The drawback is that unlike the demonstrator presented before, which enabled real-time experiences of the physical and temporal form, there is a delay between recording the performances and playing back the augmented video.

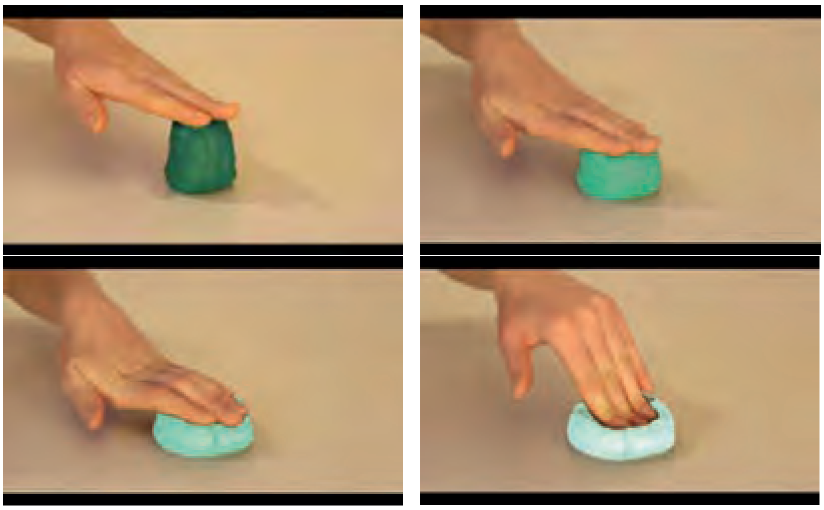

Fig 11. The changes in light intensity is digitally added to a recorded interaction with a piece of clay.

In a four-hour workshop, we tested how the Chroma keying technique might be implemented in experience prototyping the performative and expressive qualities of the LTM materials. Four designers (2 master students, 2 graduates) participated in the workshop and used the tool for prototyping their design ideas. In addition to tinkering materials to build physical mockups and color coding them (e.g., clay), the participants were given a time-line diagram to specify the plan of changes in light color and intensity over time (c.f., Janson, 2015) and/or in connection to specific performances. The time-line diagrams were interpreted and added to the recordings by the third author. The edited videos were, then, played back to the designers, allowing them to reflect on the overall qualities.

The participants found the technique simple and straightforward, yet effective in capturing the dynamic qualities. They could incorporate a wide variety of physical object around them and appropriate them, using colorful clays and stickers. The post-processing technique resulted in realistic-looking simulations of luminescent structures, however, it broke the flow of design explorations and iterations. Therefore, for the next version of the tool we decided to develop a real-time simulation of the dynamic surface light.

The Real-time version

Fig 12 shows the main components of a real-time simulation setting, namely a webcam, a screen and an input device in addition to the Chroma keyed objects. To implement the real-time simulator, we used Max MSP and Arduino platform. The former was used to perform Chroma keying and produce dynamic light behavior and the latter to register the input from the designers, to eventually alter the light behavior. As user's hands are occupied with the object, we chose to control the light behavior with feet (Fig 13). This way the users (members of a design/development team) are encouraged to actively move their whole bodies and explore a wider range of hand-gesture to full-body interactions. For this early version, we consider a limited number of dynamic light controlling features, namely, color, three fade-in/fade-out patterns (one symmetric and two asymmetric intensity variations), and speed (Fig 12, right), to generate repetitive light rhythms. A randomizer button allows for random combinations of the features (color, patterns, speed). In addition to simple sheet materials, a collection of performable Origami and Kirigami probes was made with polymer and paper sheets to benchmark structural movements.

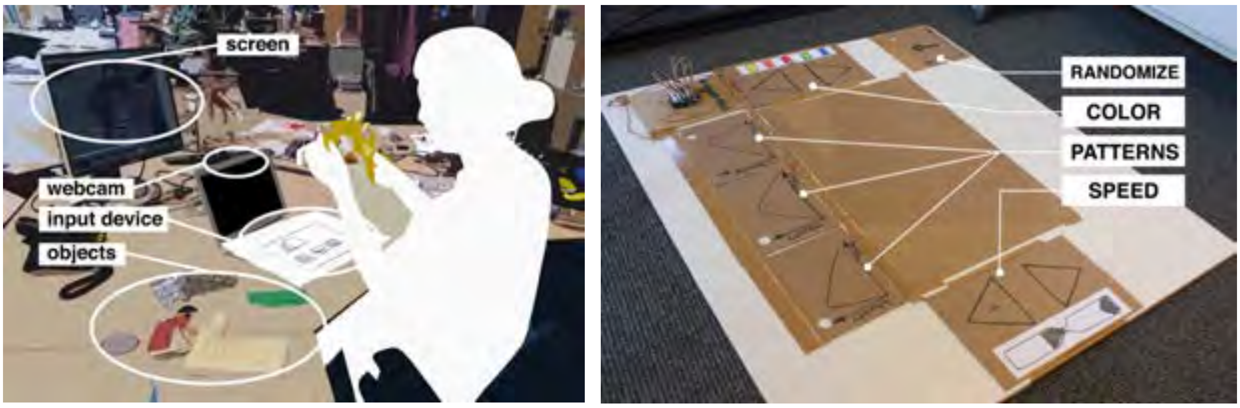

Fig 12. Left, the main components of the real-time simulator. Right, the input device to control the dynamic behavior of light.

Fig 13. The real-time Chroma key simulator in action.

Testing and Reflecting

The simulator and the performable probes were used in a 2-hour workshop to see how they might be used in understanding, exploring and communicating the experiential aspect of thin and flexible composites of piezo-resistive materials and EL materials. The 10 participants composed a mixed group of professional designers, managers, and material developers. In pairs, the participants were given 20 minutes to come up with as many as possible ways of activating EL materials in interactive smart material composites. After the initial idea generation session, the Origami probes and the real-time simulator were introduced to the participants. The pairs were instructed to iterate their design ideas (or generate new ones), and use the real-time Chroma keying tool to make animated representations of their ideas (for a duration of 45 minutes).

In contrast to the post-processing Chroma key technique, the real-time simulator was fluently used in the process of exploration. However, the features of the light input controller were found to be limited in representing the sequence of actions and events. The participants often used the papers and other objects around them to communicate their product ideas, next to their sketches. Even though we hoped that the participants invest more time in exploring the richness of material-user interactions, their time was mostly spent on contextualizing the material composite and valorizing the proposed applications. However, in using the simulator, the participants described their ideas at the level of intended interactions and the aesthetic experience. For instance, one pair used a piece of A4 with strips of the sticker to represent a flag that lights up corresponding to material deformations caused by the wind. Another pair used the stickers over a wrist splint, worn by one of them and tried to match the finger movements with the repetitive rhythm and the other way around. The more complex performances were considered only after providing the structural probes and by directly using them.

Conclusion and Future work

The approach and the tools proposed in this paper aim to support the designer’s understanding of a specific underdeveloped smart material composite, LTM materials. We argue that since these technologies are not yet at the stage for designers to be investigated directly and/or implemented across different projects, their understanding of their potentials might be limited. Prototyping their experiential aspects in the early stages of design can support the development team’s understanding of their potentials in a concrete way. To identifying the gap in capturing the dynamic and performative qualities of these composites, we first framed the experiential aspects of the LTM materials in terms of their material structure, light surface, and changes over time. Then we explored the prototyping tools used across five design cases to tangibly represent the relation between each two elements. In order to support the understanding of the experiential qualities of a unified physical and temporal form, we finally created demonstrators made of EL materials and two versions of a Chroma keying tool. Accordingly, the designers could explore the experience of dynamic light on performable structure early in the design process.

We believe that even though both the material demonstrator and the tools in the specific context of the LTM project intend to support representation and communication of an underdeveloped technology and its promising applications within the development team, the contribution is not limited to those. For instance, as by-products, these material-driven design demonstrators and digitally-augmented material probes (e.g. the clay shown in Fig 11) may inspire new materials research and product development proposals. Our broader research interest is to reach materials science communities with concrete examples of material-driven design cases and spark cooperation and exchange (see for an example Jansen et al., 2017). On a more instrumental account, the prototypes are useful in mediating discussions, specifying the objectives, and explicating the boundaries in material driven design (see Barati et al., 2016).

In a future work, we hope to identify the limitations of the simulator by further testing it and consulting the designers in the LTM project. Even though the simulator was developed to support understanding, exploring and communicating the experiential qualities of the LTM materials, it only approximates the behavior of the actual composite. The potentials and boundaries (e.g., due to production facilities) of the material development can be only verified in discussions with other stakeholders, particularly material scientists. The benefits and limitations of the simulator in facilitating the discussions between designers and material scientists should be further investigated.

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Tinkering with Mycelium. A case study.

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living materials
material tinkering
growing materials
mycelium-based material

Abstract
Creative “hands-on” experimentation with materials is a significant practice for material-driven design. It allows to understand materials, move further experimentations and generate meaningful visions. Through *Material Tinkering*, the tinkerer establish an intimate dialogue with the material, allowing the material to express its agency and letting it speaks. The material suggests and moves the designer’s choices and actions, co-performing in a proactive way, as it was alive. This is even more evident when experimenting with a living organism, e.g. mycelium, when the material is alive. How does tinkering contribute in understanding these materials? How do living and growing materials influence tinkering? We present a case study of an exploratory research through tinkering on a mycelium-based material. The qualitative results and insights bring to the understanding of the material and highlight some strategies for tinkering.

Introduction
Knowledge about materials is a fundamental element in design practice, considering technical properties and expressive, sensorial and experiential qualities (Manzini, 1986; Cornish, 1987; Ashby and Johnson, 2002; Rognoli, 2010; Karana et al., 2014). At the same time, a designerly approach to materials often leads to innovative solutions and meaningful applications. In recent years, the approach toward materials in education and practice shifted from selection to direct experimentation. Courses and workshops encourage students to experience materials through a “hands-on” approach (Rognoli et al., 2016; Groth & Mäkelä, 2016; Mäkelä & Löytönen, 2015; Ayala, 2014; Sonneveld & Schifferstein, 2009). Scholars have developed methodologies and tools for material exploration (Karana et al. 2015), drawing inspiration from Bauhaus didactic notion of “Learning by doing” (Wick, 2000) and experiential learning (Smith, 2001, 2010).
Also, designers who are focusing on material-driven innovation likely

use an experimental approach to design novel materials or reinterpret the conventional ones. This practice might be named *Material Tinkering*. *Tinkering* is a term borrowed from Human-Computer Interaction (HCI) that points to hacking and manipulating physical interaction materials in a naive, playful and creative way (Cermak-Sassenrath & Møllenbach, 2014; Sundström & Höök, 2010; Buxton, 2007; Zimmerman et al., 2007). Both the HCI community and the materials community shows interest in studying this approach concerning its implications in designer's experiential learning and engagement with the material (Falin, 2014; Niedderer, 2007; Nimkulrat, 2012; Seitamaa-Hakkarainen et al., 2013; Vallgårda & Farneaus, 2015).

Material Tinkering aims to extract data, understand material properties, understand constraints, and recognize its potentialities. Material Tinkering helps to gain knowledge about materials and to develop procedural knowledge through experiential learning. Tinkering fosters sensorial awareness of material qualities. It may reveal unpredictable and unique results as a bricolage practice (Louridas, 1999). Tinkering allows generating unique and meaningful visions by making and manipulating materials. The Material Tinkering process encourages continuous development and perpetual prototyping.Tinkerers use pictures, videos, drawing, notes, and diaries to document the process. Documentation records the process and makes the process visible, communicating it and allowing tinkerers to return to any part of the process.

In this process, materials have an active role by suggesting ways of interaction and manipulation. Metcalf (1994) argues that "the material speaks" and the designer has to be ready and open to listening to it. In tinkering, we open to material vitality from the aesthetic, affective (Bennett, 2010) and performative point of view. The material engages tinkerers on a very deep level, establishing intimacy with them Through tinkering, the agency extends to the material. The material becomes an active participant in tinkering. It co-participates in the process and co-performs (Robbins et al., 2016) with the tinkerer. As Rosner (2012) states "Materials are collaborators in the craft process", as they were alive. This is even more evident when the material is alive. A case in point is growing materials, i.e. materials or composite materials based on a living organism that uses the growth of their living organic substrate, e.g. bacteria, microbes or fungi, as manufacturing and shaping process (Van Der Leest, 2016).

A case study. Tinkering with mycelium.

One of these emerging materials is a composite material based on mycelium – namely mushroom roots – and a natural substrate derived from agricultural waste (Parisi, 2015; Parisi et al., 2016). The forming process of this material is the growing of mycelium through and over the fibers of the natural substrate, inside a mold, in several days. Mycelium acts as a binding agent to the fibers. Once baked in a oven, the material is stabilized and inert since the mycelium is dried and dead. The result is a compact, lightweight, and insulating material similar to polystyrene.

In the last ten years, it has been adopted and developed as design material by Ecovative Design, Mycoworks and other designers and companies. Officina Corpuscoli, Mycoplast, and Jonas Edvard are few of them. Currently, its commercial and experimental applications are packaging, furniture, insulation for architecture, small objects like vases, lamps, shoes, floating elements. This material is relatively unknown, and people do not know how to work with it, how it reacts to processes, to the use and to the passing of time.

The aim of this study is to understand this material through tinkering and to obtain a vision for further development, through tinkering. Another aim is to understand how dealing with mycelium influences tinkering, and which strategies and guidelines for tinkering might arise.

Fig. 1. Mushroom Packaging by Ecovative. Copyrights: Ecovative Design. **Fig. 2.** Mycelium artifacts by Officina Corpuscoli. Copyrights: Maurizio Montalti/Officina Corpuscoli. **Fig. 3.** MYX Lamp by Jonas Edvard. Copyrights: Jonas Edvard.

Fig. 4-5. Myco Make material by Ecovative. Copyrights: Ecovative Design.

Method

For this project, we used *Myco Make material*, or *Grow It Yourself material* kit, by Ecovative Design. It consists of plastic bags containing dehydrated mycelium and a natural substrate. Mycelium needs to be re-hydrated with flour and water. This kit comes with a leaflet where instructions for the process are described together with warning and safety issues (http://giy.ecovativedesign.com/wp-content/uploads/2014/08/giy-instructions2.pdf). The choice to use the Ecovative's kit is motivated by the necessity of restricting time and failure risks, and to being supported by the assistance provided by the company.

Being open source, DIY (Rognoli et al., 2015; 2016 a; 2016 b) and low-tech, it allows to examine easily and directly the process and to interact with it.

As a guideline, we used the *Tinkering with the material* step of the *Material-Driven Design method* (Karana et al., 2015). This step is crucial when technical data sheets are not available or are not completed, e.g. for experimental or semi-developed materials. We tested the material through:
- tinkering during the process
- tinkering after the process








Tinkering during the proccess

This practice aims to identify possible manufacturing processes and to understand the material behavior through the relationship between the variables of the process and the results.

Throughout four months, the process was performed six times at a pace of 2-3 weeks, producing more than 130 samples with different features. Each time, we introduced changes to the variables:
- molds shape, size, and material
- different molding techniques, e.g. pressure affects breathability
- the length of the natural fibers
- the addition of new ingredients
- the application of textures and colors
- the time of the process
- the room temperature, moisture, and aeration during growth
- the temperature and time of baking

To all these variables, the uncontrollable ones, such as the environmental ones, must be considered as they often led to unexpected results. Temperature and weather condition of the location in which the material grows could affect the results.

Tinkering after the process

This practice aims to identify the possible surface treatments and resistance of the material. We performed different interventions on the processed samples:
- texturization
- dyeing
- test for fire, water, weather and UV resistance, water resistance.
- tensile strength, scratch resistance.








Results

To answer the research question, we only report the qualitative results of our research. Through the production of more than 130 samples and the application of different treatments and variables on them, material properties and final appearance vary each time.

Ceding control

Since mycelium is a living and spontaneous material, its contribution to the process was substantial. It was not possible to have full control of it during its growing, leading each time to very different results. Imperfection, irregularity, randomness and spontaneity appears to be the main aesthetic features of the material.

These considerations on the vitality and imperfection of the material orientated the process. Rapidly, a vision emerged, and the purpose of the project became to understand and exploit the natural growing of the material and its imperfect aesthetic to enhance its spontaneity.

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The inclusion of psyllium, chia, and flax seeds brought a functional and expressive contribution. These seeds create an irregular visual pattern on the surface.

Furthermore, they release a gel that allows to shape the material without the use of molds, similarly to clay and make it more resistant.

The tactual and visual richness of the material is increased: without a mold, mycelium can grow in a larger quantity and making the material more velvety and softer, expressing its sensorial qualities fully.

Opening to the unexpected and serendipity

Unintendedly flax seeds germinate during the process, reinforcing the spontaneity of the material.

Accepting mistakes

Tinkering is a process of trial and error. Often, the experimentations brought to apparent failures, e.g. when mycelium was contaminated during the process and did not properly grow, or when mold started to grow on the material's surface due to insufficient drying. Those "mistakes" represented important discoveries about the manufacturing possibilities and limits of the material.

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Breaking the rules

The instruction given by the company gave us important notions about the preparation of the material, concerning safety issues, instruments to use, and the time required. However, we discovered that sometimes instruction did not correspond to reality. A case in point was the time necessary to bake and dry the samples, which was longer, i.e. around one hour and a half for 90°. Also, after understanding the instructions, breaking the rules was a good strategy for experimentation. For instance, we found out that storing the bags of material in the fridge for few days facilitated its growth.

Discussion

This study presents the tinkering process on a mycelium-based composite material. Through tinkering, we understood the material properties and qualities, and obtained insights to direct further experimentations. In particular, the ones related to its vitality and spontaneity contribute to carrying on the design process. From these considerations, we elaborated a vision for further developments related to the enhancement of its active relationship with time. A consequence of the process are improvements for this mycelium-based material, by emphasizing its spontaneous, imperfect and uncontrollable characteristics.

Furthermore, this study brought to indentify some strategies for tinkering. It is evident that when tinkering with growing materials, the need of a mindset arises. Tinkerers have to be humble and be aware that they cannot control everything. Since the material is a living organism, it has an active role in the design process and has a degree of spontaneity and autonomy that cannot be anticipated. We could state that comparing to traditional materials growing materials has an evident agency, that is even increased during tinkering. Aware of this the designer has to cede control and power to the material, by adapting to its will and its timing.

Together with tinker's curiosity and intuitive making, other strategies brought to unique and meaningful results:
- ceding control to materials vitality
- opening to the unexpected and serendipity
- breaking the rules and disrespecting instructions and guidelines
- accepting failures and mistakes

This experience was fundamental to test tinkering in the scope of materials understanding, exploration and design with living materials. According to the results and the insights from this experience, we had the possibility to learn how to improve the management of the tinkering process. The results and insights from this case study may contribute the creation of a toolkit of guidelines and tools to facilitate material tinkering for students, designers, makers and unskilled people, with the aims of making tinkering more intuitive and approachable, suggesting procedures, fostering creativity, and provide inspirations. In particular, dealing with living materials arises some complexity. These guidelines might suggest some technical and inspirational tips for approaching them.

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In-between of Two and Three Dimensions: Development of Fashion Pattern Cutting for Bio-fabric

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Keywords

Fashion Design
Bio Design
Sustainable Fashion
Digital Fabrication
Fashion Pattern Cutting

Abstract

There is a growing need for sustainable fashion since the 2010s. As artists and designers explore the potential use of innovative materials developed by synthetic biology and DIY bio-hacking(Myers, 2010), recent practice-led research in fashion design aims at building the better relationship between ecological sustainability and biotechnology to cope with the limited resources available on the earth(Fletcher, 2008).
Based on this issue on the material sustainability, this practice-led research analyses the current production processes of the fashion industry to propose possible solutions by incorporating emerging biotechnology and fashion design in the context of sustainable design.

Introduction

Ever since theoretical physicist Freeman Dyson said “The twentieth century was the century of physics and the twenty first century will be the century of biology” in an essay ”Our Biotech Future” in the New York Review, it is believed that biology should give an enormous impact on its environmental consequences, its ethical implications, and its effects on human welfare at the age of the coming century(Dyson, 2007).

With the help of exploration and research in the field of wearable technology particularly in the 2010s, the fusion between fashion and biotechnology is about to happen(Ginsberg, 2014). The most developed area of integration of biological processes is Material Science. In the research on sustainable materials, designers and engineers have begun to look at the metabolic processes of microorganisms as a way to synthesise natural composites. For instance, Japanese company “Spiber” is developing the synthetic yarn “QMONOS”, a yarn made by manipulating fibroin. Fibroin has environmentally sustainable characteristics and can be spun into strong and flexible yarn.

Sustainability has become a growing issue in the field of fashion design in the late 2000s and early 2010s. The commercial fashion industry highly relies on mass production and mass consumption, and the resulting accumulation of textile waste has become the root of many serious environmental problems. In the context of sustainability, this study aims to speculate an alternative sustainable form of fashion and invert the system of the current fashion industry(Fletcher, 2007).

The paper “Emerging issues in our global environment” published by the United Nations in 2011 states that especially in developed nations, the number of serious environmental problems is increasing, and the world population is estimated to exceed 9.6 billion in 2050.(UN, 2011). Population growth will obviously increase human energy consumption and would also impact the textiles and garment industries. Indeed, the global demand for garments continues to rise—the fabric consumption in 2012 was 78.88 million tons. This is around a 40 percent increase compared to the fabric consumption in 2003, and consumption is expected to continue growing. Synthetic fiber consumption was 50.14 million tons and cotton fiber consumption was 23.46 million tons in 2012. According to the World Apparel Fiber Consumption Survey by FAO(Food and Agriculture Organisation of the United Nations), the sum of the world’s fiber consumption has been continuously growing from 38.99 million tons in 1992 to 69.70 million tons in 2010(FAO, 2012).

Based on the background above, this practice-led research aims to speculate more sustainable garment design processes by examining differing stages in the manufacturing of sustainable bio fashion as a single design research project: material development and fashion pattern cutting.

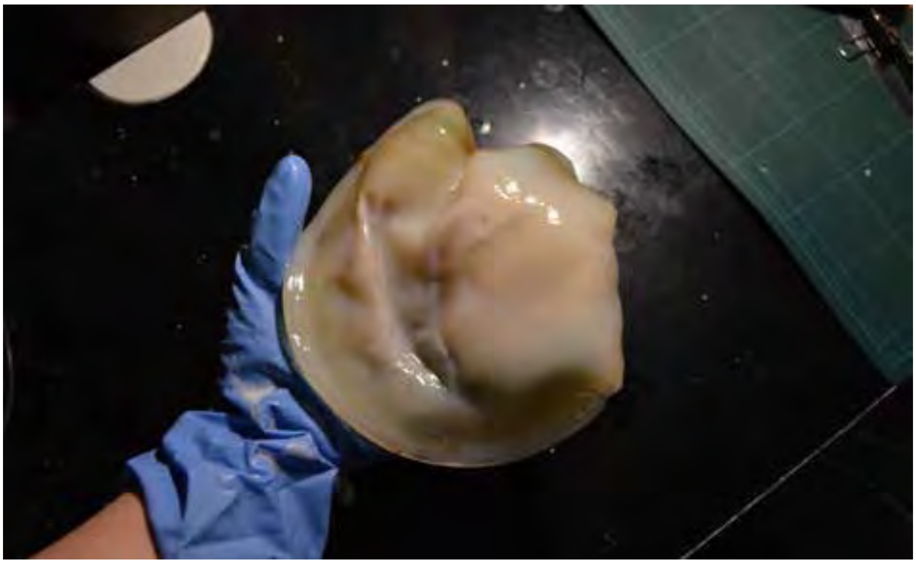
The authors have focused on development of alternative pattern cutting techniques to effectively use the material to shape three-dimensional garments while minimising fabric waste as remnants. Designers can design garments without any fabric waste using the method of “Zero Waste Fashion” (Rissanen, 2015), however, Rissanen’s proposed techniques is primarily for woven fabrics. However, a metabolic system of new bio-materials enables us to design a more organic fabric through cooperation with digital fabrication technology such as 3D modelling tool. Hence undertaken research therefore aims to improve the conventional pattern cutting techniques.

Incubation experiment for SCOBY

The authors set SCOBY (Symbiotic Colony of Bacteria and Yeast) as their object of study, practically conducted incubation experiments, recorded their process, and collected their data. The process of research is below:

1.

SCOBY is a colony of bacteria that consists of Zygosaccharomyces sp,a yeast, and Acetobacter xylinum, an acetic acid bacteria. SCOBY produces celluloses by the principles of fermentation and a sheet of cellulose is layered to expand its volume and capacity.

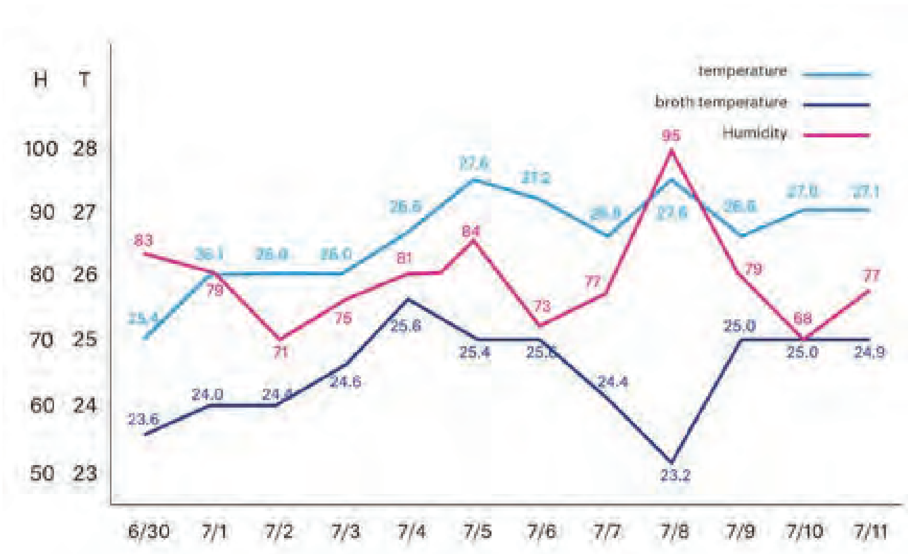


2.

Construction of Incubation Environment: The incubation environment is mainly conducted at home of the author and we made an incubator and a medium. A plastic box was used as the incubator and its size was 800*600*200mm. Medium was made from organic vinegar water, sugar, and green tea.

3.

Record of Incubation Experiments: The experiment of incubation was done for 14 days at one room of an apartment in Tokyo. We recorded the temperature, moisture, and water temperature by an infrared thermometer. Also, we noted the process of this experiment.



4.

Washing and Drying Materials: As it has been 12 days since the experiment started, the thickness of the material reached 25mm. After that, the material was taken off from the tank and we washed and dried it. After the finish of washing, the material was dried for 2 days.

2.5D pattern cutting

The process of fashion design is mainly premised on pattern cutting for two dimensions except knit and leather. However, a metabolic system of new bio-materials enable us to design more organic fabric. Based on that techniques, the current garments production process that we all are taking for granted today will radically change.

This practice improves the conventional technique of pattern cutting and invents an alternative design process. This research uses a material called SCOBY as a casestudy. It would be one of the interesting features of SCOBY that you could control its shape during the cultivation process by constructing its environment or situation. In other words, if you incubate SCOBY on a curved surface of a tank, SCOBY will produces textile along the curved shape. It would be one of the interesting features of SCOBY that you could control its shape during the cultivation process by constructing its environment or situation.

These processes in which SCOBY produces three dimensional fabric have a high affinity with digital fabrication. Also, following this method, designers can design garments without any fabric waste. Then, the authors used a large-scale technic 3D-printer that can generate human-scale objects, and created a mold in order to model bio-materials. On the mold, the authors incubated the material. The detailed process of this practice is below:

1.

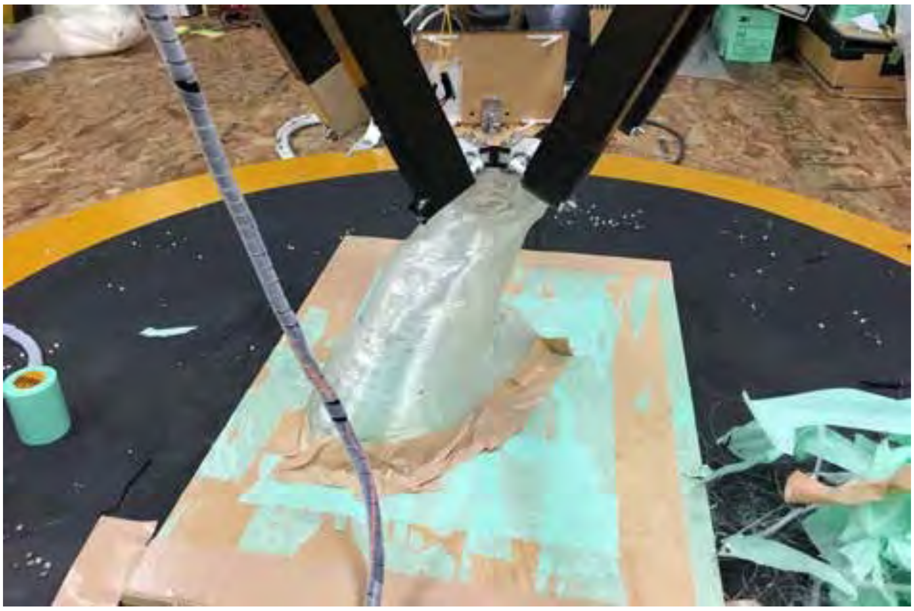
Production of the sleeve pattern: The authors made the sleeve pattern whose sleeves were impregnated with calcinated plaster.

2.

Scanning of the pattern with a 3D scanner: The authors scanned, digitised the pattern, and edited the data for printing it with a 3D printer. Also, the authors prepared different sizes such as S, M, L, and XL.

3.

Printing the edited data: The authors 3D printed the sleeve data with the 3D printer, which is specialized for large scaled data, especially for architects.



4.

Molding the biomaterials: The authors dried the biomaterials out on the cutted pattern, and molded the curved surface without straightening materials.

5.

Sewing: After drying, the authors cut and sewed the material.

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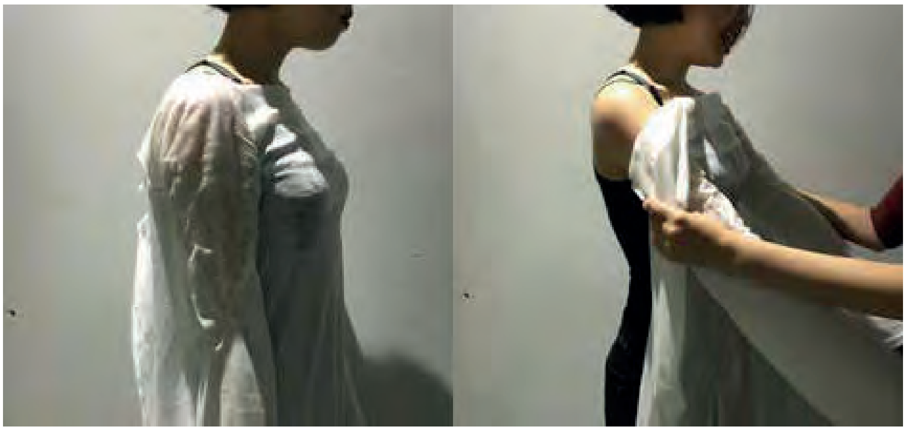
Bio Sleeve and 2.5 dimentional fashion pattern prototype.

Body Scaning by Phisical Computing

1.

In order to create carve shapes in the design phase, the conventional 2D pattern cutting is based on darts which cause many textile wastes. On the other hands, the 2.5D method enables us to change darts into molds to omit textile emissions.



2.

The scale of mold depends on available dimensions of digital fabrication machines. Then, the authors separate the data into components of garments: like the bust, waist, and hip. It suggests a use of 2D straight pattern and 3D mold in combination,

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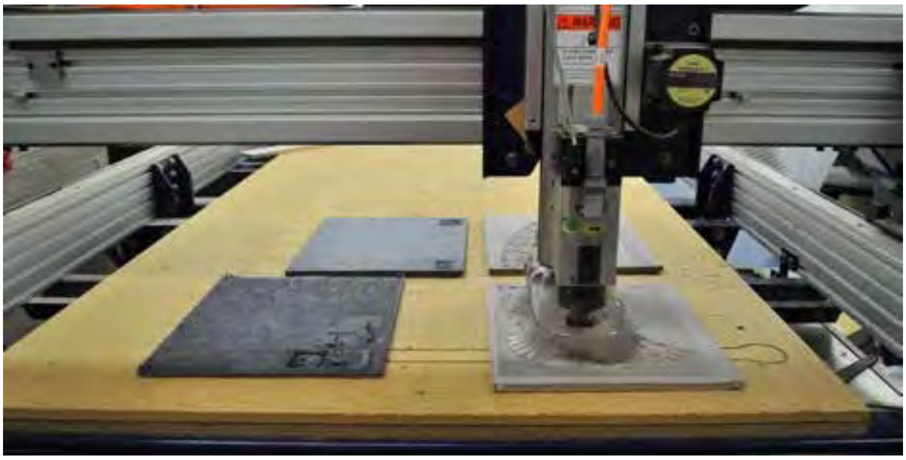
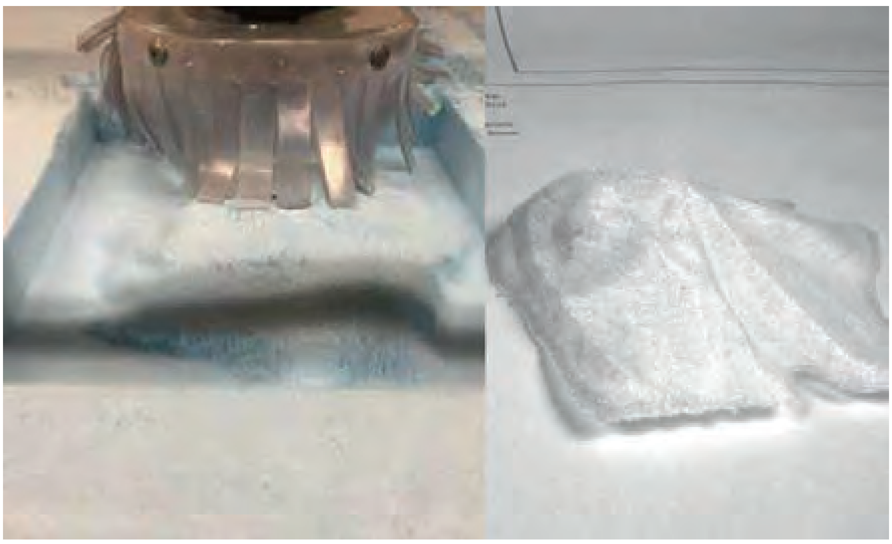
Fashion Pattern Cutting by Digital Fabrication

The authors developed parts of pattern of 3D carve shape like shoulder, bust and hip with digital fabrication tools: Shopbot and 3D printer.

The combination of 3d and 2D fashion pattern prototypes have it both ways of the zero waste method and creation for carve shape.





Discussion

So far, the research has revealed the possibilities of the 3D design process for bio-material SCOBY as sustainable material. However, several challenges still remain. For examples, the study of waterproof of the materials and the development of the garment design methodology. The ultimate goal of the research is speculation on an alternative production line toward the future of sustainable fashion.

Exhibition to speculation on an alternative production line toward future sustainable fashion.

Open Design for E-very-thing: Cumulus 2016, Open Design Exhibition, Hong Kong Design Institute, Hong Kong, 2016.10.21-10.24

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Transforming textile expressions by using plants to integrate growth, wilderness and decay into textile structures for interior

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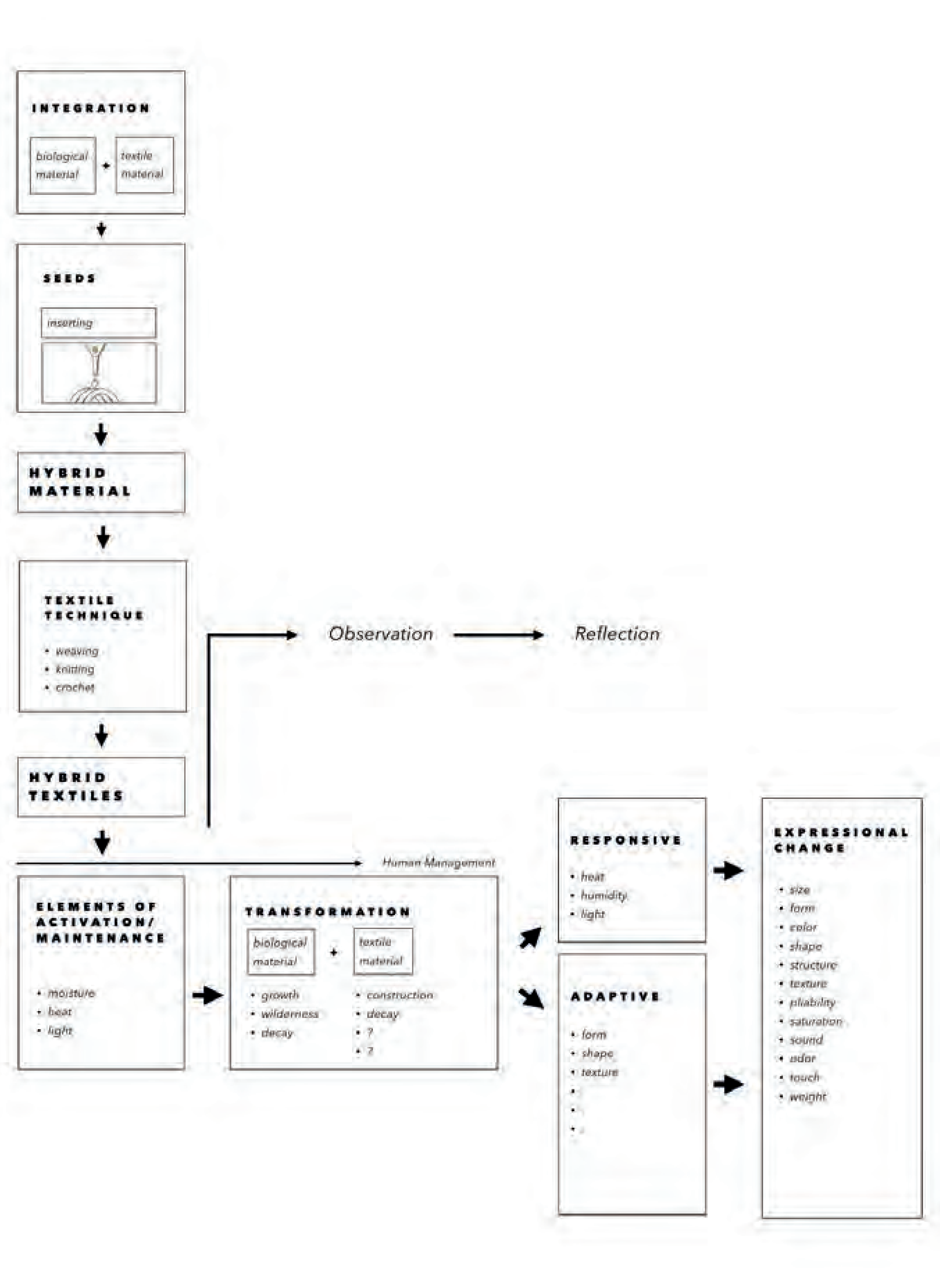
Keywords
biodesign;
dynamic expressions;
textile transformation;
living with plants;
indoor greenery

Abstract
The emergence of biodesign, as a new field in design, opens up the design process for new methods, techniques and materials, consequently these new possibilities offer special potential for the textile design practice i.e. integrating living systems into textile structures. The purpose of this work is to develop an understanding on dynamic and active expressions through using bio–based materials in textile design processes. Major placeholders are exploring new forms of plant organization, and challenging existing concepts of living with plants, focusing on surface aesthetics. By practice–based design research, the experimental design explorations will illustrate the expressiveness of growth, wilderness and decay, using moisture, light and heat as design materials. This pictorial shows seven sets of experiments that explore dynamic transformations of bio–based materials such as seeds and plants in interaction with textile materials and techniques like weaving, knitting and crochet. Consequently, the experiments illustrate potentialities in a design space where plants are placed as living materials for new processes and dynamic expressions. Subsequently, these materials open up the discussion on alternative aesthetics when designing interior textiles and designing spatial scenarios with them. The integration of living systems and dynamic expressions, especially towards growth, wilderness and decay, rises new issues i.e. their integration, maintenance, application and interaction.

Introduction
The transformative character of textiles by traditional techniques has been expanded through the development of smart materials (Worbin, 2010; Dumitrescu et al, 2014; Talman, 2015), therefore the functionality of textiles shift from static and passive towards dynamic and active expressions (Schülke, 2014). Thus, the materials potential for change becomes more essential than its visual appearance (Hibbert, 2001).



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Biodesign as an emerging field has opened new materials and methods for designing textiles and envisioning contexts of applications. As Paola Antonelli states: “Biodesign harnesses living materials (...) and embodies the dream of organic design: watching objects grow and (...) letting nature, the best among all engineers and architects, run its course” (Myers, 2014). An example of living materials in textile structures is the project BioLogic, developed by the Tangible Media Group at MIT Media Lab. It presents a textile surface using living bacteria that react to body temperature and moisture with contraction and expansion (Yao et al., 2015). Exemplary for a collaborative design process it the “Bacterial Ink” research project by Chieza and Ward. They are developing a closed–loop manufacturing system for textile dyeing and printing by using bio–pigments, produced by living bacteria (Chieza and Ward, 2015). Their collaborative research project Faber Futures aims to establish a new craft discipline through the concourse of design practice and synthetic biology. They investigate processes of co–design with living technology by manipulating textiles through folding and creasing, and introducing bacteria to create deliberate patterns. An example of responsive architecture, based on material behavior, is the project Hygroscope – Meterosensitive

Morphology. The wooden materials silent changes of movement are a result of its hygroscopic behavior and anisotropic characteristics (Myers, 2014). Scherer is fascinated by dynamics of below–ground plant parts. She is studying and manipulating root systems and uses underground templates to shape the growth of roots into a textile–like structure (Scherer, 2015).

However, more research in the textile design field is needed to develop new methods to design dynamic and active expressions by transformation over time through using bio–based materials in textile design processes and on the scale of the interior.

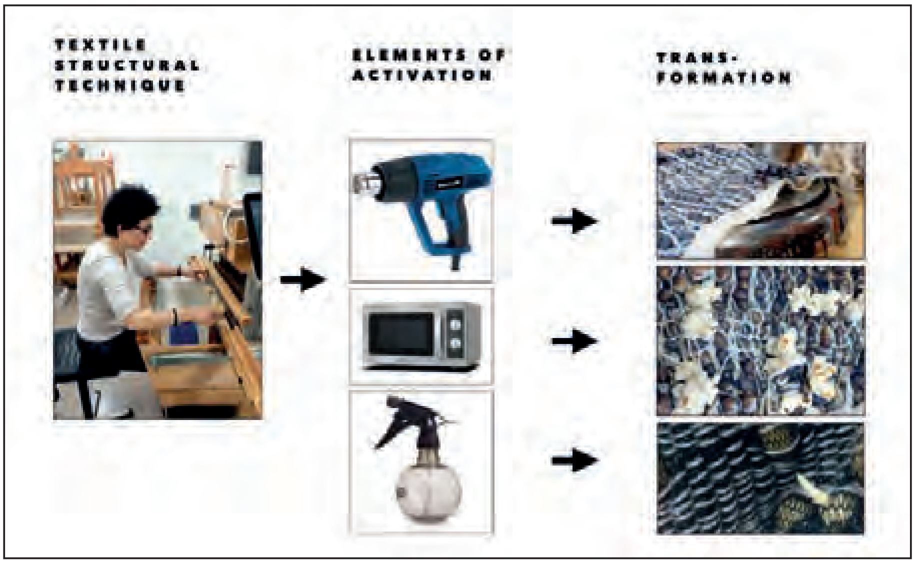
This research started out with material experiments using seeds and plants to explore potentials of expressional changes in textile structures, thus the natural parameters of plant life, from growth to decay, were explored. These parameters are activated by levels of moisture, light and heat; their change lead to processes of germinating, rooting, swelling, drying, shrinking, color–changing.

The research explores different methods to integrate plants, the following method generated the first category of experiments. A textile hybrid material consists of a biological material, i.e. seeds, plants, soil and a textile material, i.e. cellulose based yarns. The seeds are inserted into the textile material, here a tubular knitted material, to produce a system that can contain and carry the seeds for later usage within textile production processes, thus, this textile–seed hybrid material can be used to produce a two–dimensional or three-dimensional hybrid textile by weaving, knitting and crochet. Color, material of the used textile material, diameter, construction, the inserted biological material (size, shape, color, surface) and its distance in between one another are important design variables. Smaller seeds such as grass seeds could be integrated on a material–level within the spinning process for example. For scaling up the experiments, bigger tubular knits (Set 7-8) and crochet–works (Set 5-6) have been filled with soil and seeds or plants.

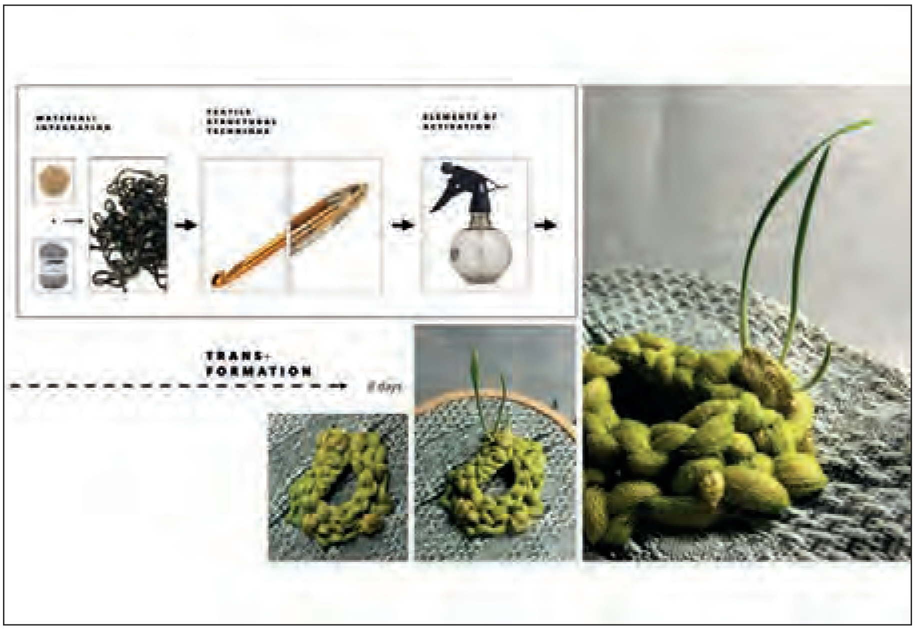
The graph shown in the beginning of this pictorial illustrates the order of the examples, from hybrid material to hybrid structure, from Set 1 - Set 7 and concludes in forms of human management.

Set 1 shows corn, introduced into a tubular knitted material made from cotton and polyester. The cotton–corn material has been heated in a microwave, popped and expanded the tube. The corn-polyester material has been sprayed with water, roots were developing after two days. The experiment was directed to explore the transformation of a material that unactivated can be used in textile constructions. The corn was chosen due to its potential of reacting to heat and moisture.

Set 2 shows a prev. described cotton–corn material used in hand weaving. It has been activated by a heatgun (4mins), a microwave (2x2mins) and a water spray bottle (2x/day). The experiment explores 3 forms of activating a cotton–corn–cloth and its transformation/disruption over time. The popcorn–cloth turns brownish, expands broadly, has a sweet smell, the sprouting cloth has an earthy smell, and sharp, green sprouts.

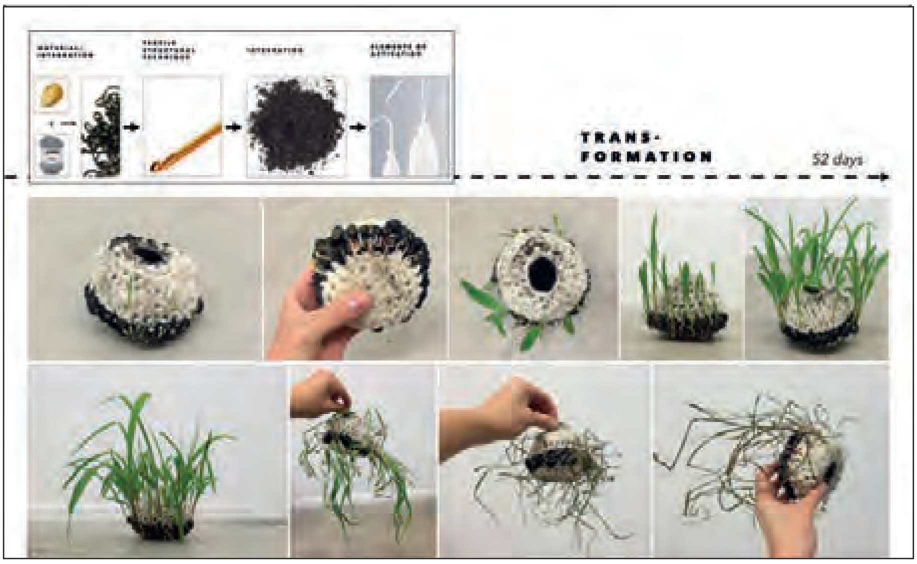


Set 3 shows a cotton–barleygrass material crochet onto a weave. The barley grass was chosen due to its fast growing process and its nutritional value. The textile has been activated by regular watering with a spray–can. Due to the green colored cotton–barleygrass material and its sprouts, the first changes and the contrast between the plant–parts and the textile design are subtle, thus they are aesthetically interwoven and blend into one another.

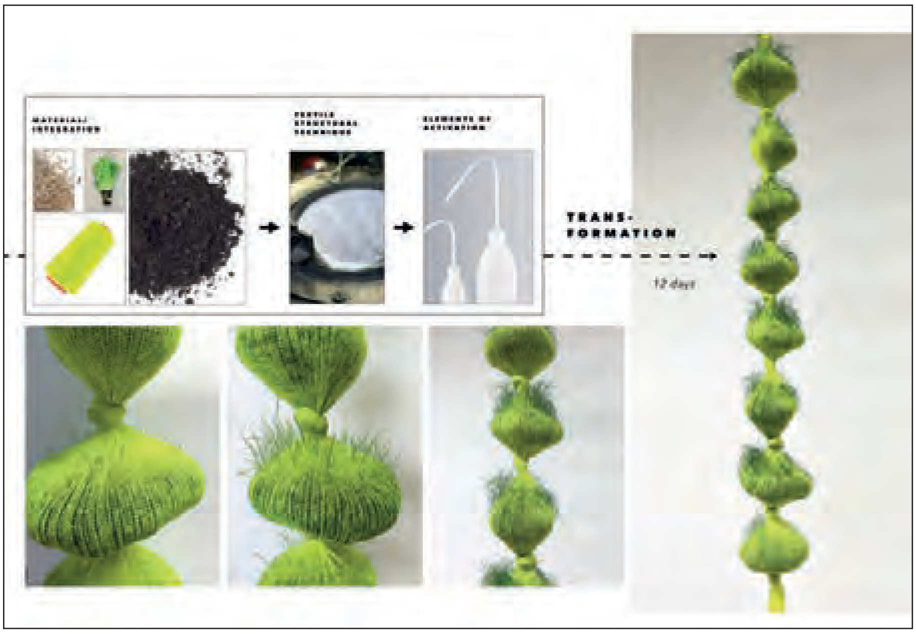


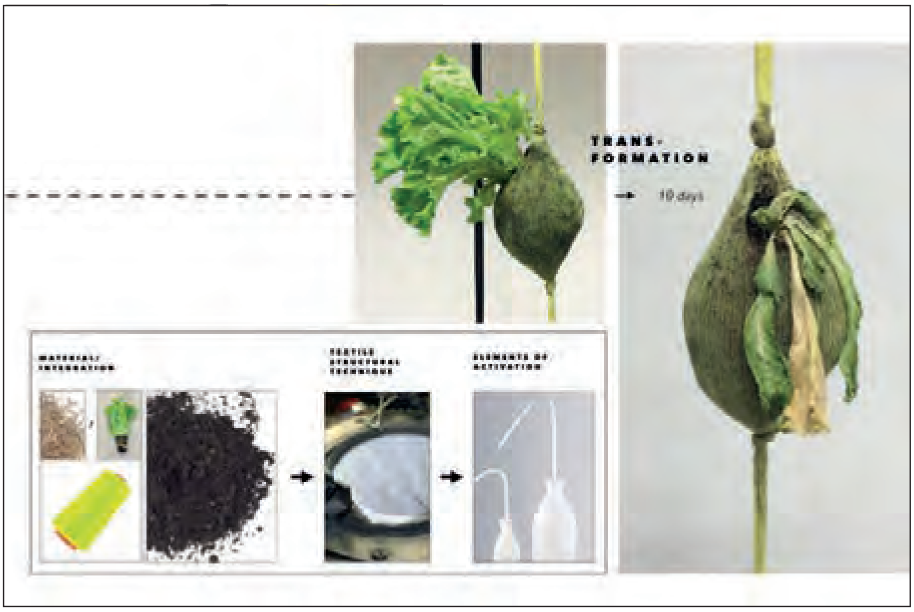
Set 4 shows a wool–corn material crochet into an organic form. The woolen tubular knit was chosen due to its material qualities and the fine construction that highlights the corn. Activated by regular watering, the outgrowth of roots positioned, stabilized and enlarged the object towards the ground and sides. The up–reaching sprouts transformed its soft expression, form, color, size and materiality.

Set 5 shows a textile container crochet from wool and a cotton–corn material, forming a ring around the soil containing object. Regular watering into the object started the growing. White and red roots grew underneath and inwards. Stopping the watering initiated the drying process which transformed the material again, changed color, pliability and direction of the leaves, their sound and the objects weight.



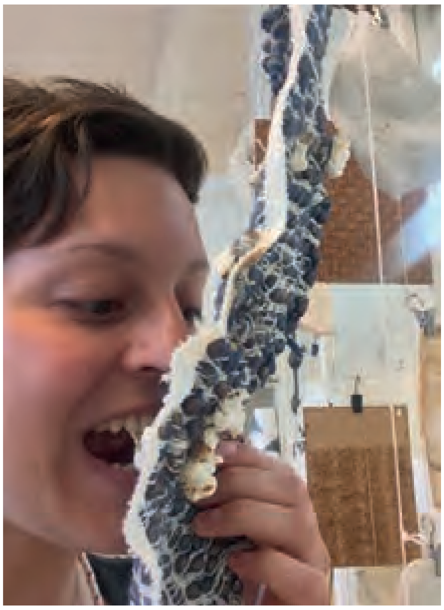
Set 6 shows a tubular knit from Polyester, filled with soil and grass seeds. The textile materials was chosen due to its color, the grass due to its potential to cover an entire surface. The outgrowing grass covers the up–facing parts of the structure like a fur. Its density increased, the expression transformed from subtile to more expressive, from glossy, bright green and straight to fuzzy, dark green and distorted due to the initiated drying process.



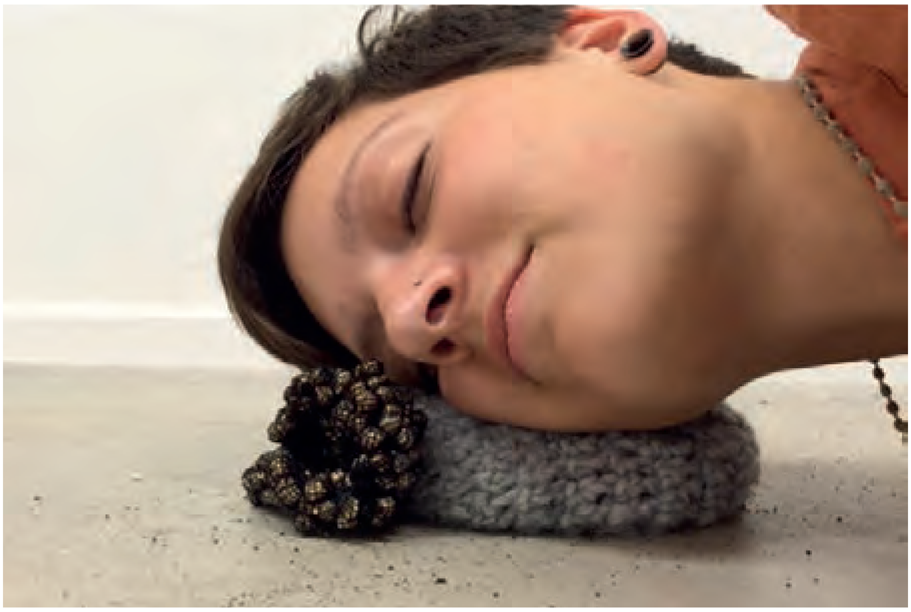


Set 7 shows a tubular knit from Polyester, filled with soil and planted with lettuce. As in Set 6, the tube was expanded and shaped by the contained soil and manipulation. Through a hole in the structure the lettuce could be planted and the structure watered. The neon–yellow color of the knit was dampened by the soil that penetrated the construction. The vertical, threedimensional structure can be altered, reshaped, expanded, and repositioned easily, due to the flexible construction of the knit. The structures main transformation is expressed by the withering lettuce–leaves, hanging down, nestling to the structures form and downwards. The leaves first strong and upwards but pliable, turned weak and adapted a textile–like character, by its folding, wrinkling, hanging leaves. Their color, bleached by the drying process, matched up with the color of the structure.





Both, the biological material and the textile material, transform over time, due to their distinct material qualities. The biological material, seeds for example, will express different states of plant–life, in this context described as growth, wilderness and decay. These transformations open up for people–plant–interaction which is summarized as human management and includes activities such as observing, manipulating, harvesting, draping, touching, cutting, braiding. The transformation itself and the human management lead to expressional changes on the different levels/ scales that can be perceived as adaptive and responsive and expressed by changes in size, form, color, texture, pliability, weight and odor, to name a few.



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Discussion

The use of knitting, weaving and crochet, as illustrated in this picorial, offer different qualities to embedding seeds and plants and to provide a growing matrix or to disrupt the expressions of the constructions. Knitting was used to explore flexible, more spacial and threedimensional constructions. The density and the position of the knit influence the outgrowth of the germinating seeds. The material effects the water distribution and the reaction to moisture, heat and light. Crochet was used to explore free–formed threedimensional shapes that resemble with common plant containers but differ by using the textile–seed material to form the soil–containing structure. Hand–weaving was used to explore the transformation of twodimensional constructions. When using corn, the form of the activation makes a significant difference., as well as the position of the cloth.

By embedding the potential of growth into textile structures, the interaction of cloth and plant/s evokes. The illustrated examples indicate various transformations, expanding and altering textile expressions by adding organic disturbances to former complete forms, structures or textures. Set 1, 2 and 6 illustrate disruptions of the construction of the cloth whereas Set 5 - 7 provide a living matrix for growing plants, by using soil as a substrate. Set 4 exemplifies a threedimensional transformation of a textile object and Set 5 displays a complete biological lifecycle from growth to decay. Consequently the transformations can vary in their diffusion and density and are mostly unique and irreversible. In contrast to the project Hygroscope, the proposed hybrid textile material system is aligned, based on textile techniques, constructions and applications. The difference to the project Bacterial Ink is the production that doesn´t require special environments such as a laboratory and sterile conditions. Another difference are the two general states: passive and active. Whereas the wooden materials hygroscopic behaviour and anisotropic characteristics initiate the silent changes of movement, which is more a static and dynamic expression, the activation of the hybrid textile material system starts a process, comparable to a chain reaction that is not reversible and increasingly erratic as the complexity of the material system expands and the scale increases.

Consequently the presented examples provide perspectives on textile structures for interior that can be edible - degradable, passive - active, promote a symbiotic reltionship between human and plant through the textile and a biological lifecycle. Especially the integration of seeds open up potentials for using unactivated structures on the scale of the body or in interior settings. Thus, not only the stable and passive structures challenge new forms of interaction, the activation becomes an open field for exploring interactions as well, using moisture, light and heat as design materials. The parameters of life, from growth to decay, open up for interactions regarding maintenance, i.e. watering, cutting, harvesting and regarding i.e. eating, manipulating, arranging.

This research illustrates potentialities in a design space where the living material is placed as dynamic material for new processes and expressions; a potential design space where the dynamic and transformative materiality give textile design a bio–based dimension in the design process. Thus, biological materials such as plants and seeds in particular, are used as natural smart materials used to develop new textile materials and expressions. Subsequently, these materials open up the discussion on alternative aesthetics in interior spaces when designing textiles and spatial scenarios. Expressions of wilderness and decay challenge the limits of conventional textile and interior design and promote a discussion about future forms of living with plants that ranges from textile design to indoor gardening.

The further practical work will consist of experiments and scenarios that concentrate on the interaction of plant and textile construction, suggest different forms of human management and promote an extended lifecycle that results into a biocycle by focusing on pure cellulosebased fibers. The potentials of industrial weaving for plant–containing structures will be explored by using pocket–weave constructions Therefore sprouts will be used, as they grow fast, demand little, come in different shapes and colors and can be trimmed, harvested and eaten.

Conclusion

As pictured, textile materials, techniques and constructions will be of foundational use to interweave interior living and plant organization in a hybrid environment that is managed by humans. To create alternative expressions of static and dynamic qualities, „Farming Textiles“ proposes biological materials such as plants and seeds in particular, as natural smart material for using in textile design processes to develop new textile materials. These materials open up for a new range of interactions, since human management is part of their maintenance and transformation. These forms of interactions and conditions redefine what is understood as behaviour and prevailing states indoors, the present definition of interior is challenged and open for discussion. „Farming Textiles“, as an artistic research program, is not directed to develop functional solutions, it aims to propose future perspectives in forms of living with a hybrid of interior textiles and a diversity of local plants. Seasons and lifecycles are usually not expressed in interiors, especially Subnatures and processes of degradation are not considered as experiences of beauty and enjoyment, they are expressions of evanescence and imperfectionism. They are often seen as threatening, uncomfortable and a disturbance of a pleasant atmosphere. As a side–effect of „Farming Textiles“ materials and processes, interactions and transformations, a range of Subnatures such as mud, dust, puddles and insects can occur and challenge the understanding of a comfortable space. Thus, they force a confrontation with the prevailing relationships to the environment.

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Growing materials for product design

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Abstract

The possibility to fabricate materials from living organisms offers appealing advantages for product design, such as higher sustainability and an interesting novel aesthetics. Several designers are now ‘growing’ their own materials. Despite the large interest shown, this emerging material practice is still scarcely understood in design literature. The aim of this paper is to shed light on what it means to design with growing organisms as collaborators, identifying the defining traits of this novel, designerly way of ‘doing materials’. To do so, we first compare this specific approach to the approaches of others working in the intersections of biology and design. In this way, we outline the boundaries of Growing Design, defining its unique characteristics. We then provide detailed descriptions of three classes of Growing Materials: fungal, bacterial and algal materials. For each class, we bring two examples of designers utilizing these materials for industrial design purposes. This helps to further explain what truly distinguishes Growing Materials from other conventional materials and to understand the challenges in working with them. Finally, this discussion enables us to set out a research agenda for Growing Design, supporting the development of these materials for industrial production.

Keywords

Alive Materials; Mycelium; Bacterial cellulose; Algae; Materials Experience

Over the last decade, designers have started fabricating new materials by utilizing the natural processes of growth and reproduction of living organisms such as fungi, bacteria and algae. Among others, the works of Suzanne Lee (BioCouture) and of Maurizio Montalti (Officina Corpuscoli) were pioneering in this new field at the intersection of design and biology. In the case of BioCouture, Suzanne Lee developed a collection of garments that were grown from bacteria by the fermentation of sugar and green tea (Lee, 2011). In his ongoing project, Maurizio Montalti explores strategies to employ mycelium (the ‘alive’ agent of fungi) for the production of novel materials and to explore alternative manufacturing techniques. Both designers achieved to develop a range of materials with different characteristics, from paper-like to leather-like, which offer promising technical properties and aesthetic qualities (Montalti, n.d.).

This approach to materials for product design originates from the advances in biotechnology, which were originally developed for the fabrication of biological tissues, such as skins and organs for medical purposes (Mironov, Trusk, Kasyanov, Little, Swaja, & Markwald, 2009). With the democratization of science and manufacturing technologies (Rognoli et al., 2015), biofabrication has become relatively accessible to non-experts. The fascinating opportunity to co-create with Nature, the diverse forms of expressions that can be achieved, and the possibility to reimagine the paradigms of production motivate the cross-fertilization of biology with art, architecture and design (Antonelli, 2012).

‘Growing Design’ (Montalti, n.d.; Ciuffi, 2013), which we define as the fabrication of materials and products from living organisms, can be considered as a type of “*DIY material practice”* (Rognoli, Bianchini, Maffei & Karana, 2015)*.* ‘DIY materials’ are designed and created through individual or collective self-production practices, often by techniques and processes of the designer’s own invention (Rognoli et al., 2015). Through this lens, it is possible to identify other potential motivations that trigger the interest of designers towards Growing Design. These are: the opportunity of novel aesthetics, in contrast with the standardized model of perfection of industrial products; and the willingness of designers to have a self-controlled production process from the material development to the embodiment of a product (Rognoli et al., 2015).

All the reasons listed above have made the process of growing materials extremely appealing to designers. The amount of design exhibitions (e.g. Fungal Futures, NL: Montalti, 2016; This is Alive, FR: Collet, 2013), conferences (e.g. Biofabricate, NY: http://www.biofabricate.co/) and journals (e.g. Pavlovich, Hunsberger, & Atala, 2016; Mironov et al., 2009), as well as the establishment of online communities (e.g. Growing Materials, 2016) and bio-labs (e.g. Open WetLab at Waag Society, NL: Evers, 2016) are clear indications of the increasing amount of interest among design communities toward the production of materials from living organisms.

Despite the large interest, the phenomenon of Growing Design is still scarcely understood. The lack of a clear vocabulary and the confusion with other approaches that merge biology and design are evidences of this issue. In this paper, we aim to define what the practice of Growing Design is about, gaining more knowledge on what type of materials are grown for design purposes and how the process of fabricating them unfolds. We will first position Growing Design among other approaches that merge biology and design. This will give us a refined definition of the Growing Design practice. Furthermore, we will elucidate on three classes of materials derived from living organisms, namely fungal, bacterial and algal materials, to explain their unique opportunities for product design.

When Biology Meets Design

Next to Growing Design, there are other approaches looking at the possibility to employ natural systems for design purposes. These approaches question the various roles that Nature can take in design, such as in rethinking the production of artifacts in a more efficient/sustainable way (e.g. biomimicry: Benyus, 1997; Cradle-to-Cradle: McDonough & Braungart, 2010). They are often grouped under the notion of BioDesign (Myers, 2012), which is described as "*the emerging and often radical approach to design that draws on biological tenets and even incorporates the use of living materials into structures, objects and tools*" (Myers, 2012, p.8). In a recent UK-based residency program named 'Synthetic Aesthetics', professionals of diverse backgrounds, such as design, art and biology, investigated the variety of approaches that designers can take to design Nature itself, with a special focus on the possibilities offered by synthetic biology (Ginsberg, Calvert, Schyfter, Elfick, & Endy, 2014). Yet, these approaches present nuanced differences in how actively (or passively) Nature is employed in the design process. For example, Carole Collet grouped 34 innovative projects under five categories based on their possible relationships with Nature: 1) Nature as a model (referring to designers as "The Plagiarists"); 2) Nature as co-worker in design process ("The New Artisans"); 3) Nature as reprogrammed and synthetic ("The BioHackers"); 4) Nature as hybridized with non-living technologies ("The New Alchemists"); 5) Nature as conceptualized and imagined in a provocative far future ("The Agents Provocateur") (Collet, 2013).

We position the notion of Growing Design under the second theme proposed by Collet, considering Nature as a co-worker in the material design process. The first category of the Collet's taxonomy, which refers to Nature-inspired design, uses Nature's principles to inspire ideas for new materials, forms and structures (Oxman, 2010), yet does not directly involve the use of biology, and, as such, of any living organisms. Accordingly, we identify four main material design practices at the intersection of biology and design: 1) Growing Design; 2) Augmented Biology; 3) Digital Biofabrication; 4) Biodesign fiction. Figure 1 depicts these practices and maps few related cases to this taxonomy. We retrieved these cases by screening two published books (Myers, 2012; Ginsberg et al., 2014), recent exhibitions (Collet, 2013; Montalti, 2016), online communities (Growing Materials, n.d.), design blogs (www.dezeen.com) and scientific publications (Bader et al. 2016; Oxman, 2015).

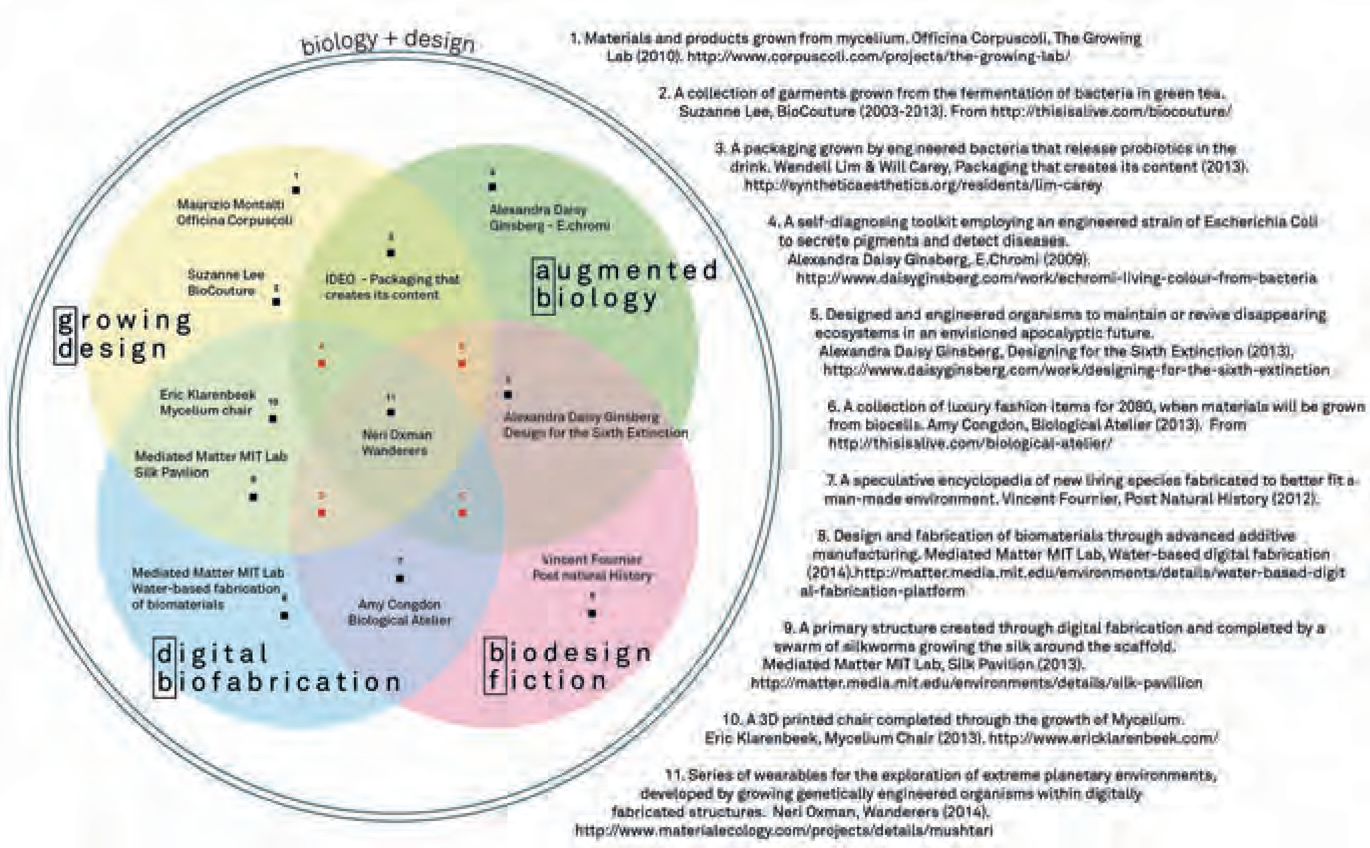

Fig 1. Mapping the four approaches using biology for design purposes.

Under ‘Augmented Biology’, we group cases that explore the potential of re-engineered cells for contemporary societal challenges, such as famine, disease and energy shortage (Collins, 2012; Agapakis, 2013). Specifically, designers working with this approach employ synthetic biology, i.e. the manipulation of living organisms using engineering principles like ‘standardization’. Synthetic biologists aspire to redesign Nature to achieve faster, repeatable and more predictable results (Ginsberg et al., 2014). To do so, they seek to alter the organisms’ genetics, either through genetic programming or other forms of mutagenesis. With Augmented Biology, Growing Design shares the ability to descend at the micro scale, to control the material’s variables and achieve the intended qualities. However, Growing Designers do not directly engage in the re-design of Nature, as they only employ existing genomes and seek to adopt Nature’s strategies of production, instead of redesigning them through engineering principles.

Designers working with Digital Biofabrication stretch the possibilities of what design can do with synthetic biology even more, by adopting computational tools and advanced technologies. In this approach, Nature is hacked through digital fabrication to breed new “ecologies of materials” (Oxman, 2015). By combining additive manufacturing, digital technologies, and mathematical modelling tools, these designers achieve a ‘digitally-inspired’ Nature, in contrast to the conventional notion of Nature-inspired design (Benyus, 1997; Oxman, 2010). In Digital Biofabrication, computational tools are used not only as fabrication means, but also to model how the living organism will behave. It does not necessarily involve the alteration of the natural genomes, as in the case of Augmented Biology. Nonetheless, its use of computational tools and advanced technologies, and its focus on Nature as object of design process differentiates Digital Biofabrication from Growing Design, which is rooted instead in making, crafting and tangible practices.

When designers who work with biology envision a far, provocative future, they adopt the perspective of BioDesign Fiction. Generally, BioDesign Fiction generates highly conceptual visions of our interactions with living, natural ecosystems in the far future. This approach is grounded in Speculative Design (Dunne & Raby, 2013; Sterling, 2005). The practice of Growing Design is rooted instead in the analysis of the present manufacturing paradigms, working toward the development of new ways to sustain our existence.

So far, we have described a neat separation between the approaches coupling design and biology. However, many recent examples combine a number of them, as, for example, the case of the 3D-printed *Mycelium chair* by Eric Klarenbeek (2016). In this case, the designer used additive manufacturing to print a scaffold on which the mycelium can grow. This example couples advanced technologies with a growing organism, thus falling under the intersection of the Growing Design and Digital Biofabrication approaches (Figure 1). Cases with such nuanced identity are very common, combining multiple perspectives to reach the intended design purpose. Using this taxonomy, we can even speculate on possible future cases, as identified in Figure 1 (in red) by points (A), (B), (C), and (D). For example, at the intersection of Growing Design, Augmented Biology and Digital Biofabrication, we anticipate the fabrication of materials by growing genetically modified organisms, whose behavior is tailored by the designer through a computational algorithm. Similarly, at the intersection of Growing Design, Augmented Biology and BioDesign Fiction (B), we envision that the future plants could be genetically programmed to produce “superfoods” along with materials for man-made artifacts – similar to what was already conceptualized by Carole Collet in the project *BioLace* (Collet, 2013).

The presented taxonomy has helped us to reflect upon the distinct characteristics of Growing Design as follows:

1. Designers cooperate with Nature to achieve specific design purposes
2. The materials employed in Growing Design are grown from living organisms
3. Designers do not alter the genetic structure of the living organisms
4. Designers actively engage in growing the materials (DIY)
5. The fabrication process is rooted in crafting and making
6. The material is envisioned to be used in products today or in a probable future

This list identifies few traits that manifestly characterize the practice of fabricating materials for products from living organisms. Having detailed these qualities, we now seek to understand what are the unique opportunities that Growing Materials offer to product design. In the next section, we will describe three classes of materials fabricated from living organisms, providing illustrative cases for each material class.

Growing Materials from Living Organisms

Although organisms like chitin or protocells can be used in Growing Design (Alper, 1992), in this section we focus solely on ***mycelium (fungal materials), bacteria and algae***, as these three groups of organisms are used relatively more by designers.

Fungal Materials

With the term ‘Fungal materials’ we define materials derived from *mycelium*. ‘Mycelium’ is a network of interwoven, thread-like hyphae that constitute the vegetative part of mushrooms (Kavanagh, 2011). Fungal materials are grown by two alternative methods: either exploiting the abilities of mycelium to interlock other substances within its network, forming a bulk material (mycelium-based composites), or harvesting a liquid culture of mycelium (pure mycelium). For mycelium-based composites, the substrates used can span from agricultural waste to sawdust, to orange peels or any organic element that can provide nutrients to the mycelium. The choice of the substrate has a significant impact on the final material, as it influences both the technical properties and the *experiential qualities of the material* (Karana, 2009; Giaccardi & Karana, 2015).

Pure mycelium materials are instead fabricated from a liquid culture, in which the mycelium is provided with the right nutrients (the 'minimal medium') necessary for its growth, and maintained in static or machine-shaken containers. The resulting substance forms thin, leather-like sheets of material, which can vary in properties, depending on the nutrients provided. For example, different colors and translucency effects can be obtained adding chemicals (e.g. glycerol or ethanol) to the liquid culture (Blauwhoff, 2016).

In order to obtain appropriate results and prevent infections by other organisms, the fabrication of fungal materials requires the sterilization of the growing environment, including the substrate on which mycelium should grow. The process always starts with a growth of mycelium on a base-plate. From this, it is possible to inoculate the substrate in the case of mycelium-based composites, or to initiate a static or agitated culture. Depending on the intended results, the growing process can last two to three weeks. To ensure the growth of mycelium, it is necessary to create a controlled environment, in which the temperature and moisture are maintained stable. Depending on the strain of fungi, these conditions can vary from 25-30°C in temperature and 60-65% in humidity. At the end of this process, the mycelium can be killed by drying the material at 60°C, or left in 'hibernated' state, preserving the possibility of future growth.

Manufacturing of products starting from mycelium-based materials is possible through different techniques, including conventional processes as CNC cutting, milling, laser-cutting, etc. Other unique opportunities are offered by the materials' features: for example, as mycelium-based materials can grow into the shape of the container used to fabricate them, molds of the same shape of the final product can be used as growing environment. Below, we present two cases illustrating how fungal materials are used in design.

The Factory of the Future – By Emma van der Leest, Zoe Agasi and Loeke Molenaar

Fig 2. "The Factory of the Future" – a concept of sustainable packaging made from a mycelium-based composite, developed for the circular-economy-based farm 'Uit Je Eigen Stad'.

This project was commissioned to three graduates of the Willem de Kooning Academy by the company Uit Je Eigen Stad, a city farm in Rotterdam focused on circular food production (van der Leest, Agasi, Molenaar, n.d.). The project aimed at the development of sustainable packaging for the company, to replace the conventional plastic packaging. The designers developed a concept based on a waste stream of the farm, which occurred during the cultivation of Shiitake mushrooms and vegetables. The designers re-used the hemp mats that was previously employed to harvest vegetables and were no longer useful. Nevertheless, these hemp mats could still provide sufficient nutrients to be qualified as a substrate to grow the Shiitake mushrooms. Furthermore, designers envisioned that the hemp mats, after being reused for the cultivation of Shiitake, could be recycled once more as substrate to start the fabrication of mycelium-based composites, which eventually enabled them to create a more sustainable packaging for the farm's production of vegetables (Figure 2). The material developed is fully compostable, with good thermal insulation properties. It is also highly water repellent. In this particular case, the designers intentionally designed a process to tie the company's loose ends and improve the sustainability of the food production system.

MycoTEX – By Aniela Hoitink (Fungal Futures)

The project has been developed as part of the NWO-funded project 'Mycelium Design', in which several artists and designers experimented with mycelium (Montalti, 2016). One of the designers, Aniela Hoitink, used pure mycelium to make textile-like materials for garments (Figure 3). The dress concept is fabricated by forming different modules of the dress from pure mycelium directly on the body, a solution that yields for easy repairs and adjustments and is showing a new production process for manufacturing clothing.

Fig 3. "MycoTEX" – development of pure mycelium as textile for garments.

Bacterial Materials

Several design projects investigated the use of bacteria in the fabrication of materials for product design. When provided with the correct nutrients and growing environment, some species of bacteria produce a layer of cellulose, which differs in its properties from the cellulose derived from plants. Specifically, the compound derived from bacteria is almost pure cellulose and contains no lignin, which makes it flexible and consequently, easier to mold and process than plant cellulose (Iguchi, Yamanaka & Budhiono, 2000). The formation of cellulose is triggered by the symbiotic culture of bacteria with yeasts. The bacteria, when placed in the nutrient medium, produce subfibrils and subsequently microfibrils, forming a thick layer of cellulose floating on the medium surface (Iguchi, Yamanaka & Budhiono, 2000). The *Acetobacter Xylinum* is the most widely used strain of bacteria for applied studies such as in product design, although several other species are known for their abilities to produce cellulose (Huang, Zhu, Yang, Nie, Chen & Sun, 2014; Ng & Wang, 2016)

The process of growing bacterial cellulose starts from the fermentation of bacteria in an acidic nutrient medium (pH=3), containing either glucose, fructose or glycerol (Iguchi, Yamanaka, Budhiono 2000). The growing process, similar to that of pure mycelium, can be activated in static or agitated (i.e. machine-shaken) conditions. In product design, bacterial cellulose is normally harvested in static conditions in tanks or containers that can allow the fabrication of large sheets of material (Lee, 2011). The growing process requires a sterile environment to prevent the formation of by-products such as moulds and/or to spoil the culture with other strains of bacteria. To ensure the formation of cellulose, the optimal conditions are a temperature of 28-30°C and scarce direct sunlight. After two-three weeks, a layer of material forms on the surface of the solution. The growing process can then be prolonged in order to achieve a thicker material, or stopped by collecting the cellulose sheet and washing it with water and soap. At this stage, the material is dense with water and needs to be dried on a flat surface or on a three-dimensional mold. During the drying process, the cellulose will release the excess water and decrease in thickness, acquiring its true experiential and technical properties such as color, thickness and surface appearance. Depending on the type of nutrients the medium provides and the strain of organism used, the type of material derived can vary significantly. It can be fabricated as thin paper-like layers with a soft and matte surface, or as thicker, leather like materials.

Different techniques can be used to process the bacterial cellulose and manufacture products with it. Along with conventional shaping technologies, such as laser-cutting, sewing and blow-molding, other possibilities are prompted by inducing shape formation during the fabrication process or during the drying phase by using 3D shapes. For example, some design cases investigated the possibility of growing bacterial cellulose directly into shapes (see the project Xylinum Cones, Hülsen, n.d.) or by rotating a 3D shape mold into the fabrication tank (Ng & Wang, 2016). Moreover, the growing abilities of the organism can be employed to make self-assembling materials, which bind together during fabrication and growth processes.

Xylinum project – By Jannis Hülsen and Stefan Schwabe

In the project Xylinum, Jannis Hülsen and Stefan Schwabe explored the use of the Acetobacter Xylinum to grow everyday products with different production techniques (Hülsen, n.d.). They experimented with few techniques to produce bacterial cellulose directly in three-dimensional shapes, ranging from basic conic shapes to the complex form of a stool (Figure 4). Their intention was to combine the cooperation with microorganisms and the reproducibility of objects, finding a balance between industrial precision and organic formation (Rognoli et al., 2015).

Fig 4. “Xylinum project” – growing bacterials cellulose directly in 3D complex shapes.

Invisible Resources – By Zuzana Gombosova

In the project ‘Invisible Resources’, Zuzana Gombosova explored the diverse roles that bacteria could take as ‘white biotechnologists’ such as acting as assemblers, generators or catalysts of growth (Figure 5, left). Beyond this categorization, Zuzana experimented with different techniques and nutrients to grow bacterial cellulose. She developed a collection of furniture to demonstrate the material’s qualities (Figure 5, right). The products are not fully functional because of the material’s high degradability. Yet, the ability of bacterial cellulose to constantly transform and change properties over time is interpreted by the designer as a way to question our sense of value for materials embedded in everyday products (Gombosova, n.d.).

Fig 5. “Invisible Resources” – research on the potential of bacteria as collaborators of manufacturing process (left). One element of the furniture collection “Made by Invisible resources” (right)

Algal Materials

With the term ‘algae’, we identify a large group of photosynthetic organisms that are not singularly classified into one biological domain. The majority of algal species are eukaryotic organisms, thus belonging to the same biological domain of fungi, plants and animals (Brodie & Lewis, 2007). However, some organisms that belong to the domain of Bacteria are generally included in the group of algae, e.g. cyanobacteria – the so-called ‘blue-green algae’. The use of algae for the production of artifacts, materials, chemicals and fuels has been investigated for centuries. Algae offer a promising and almost inexhaustible resource to sustainaible alternative production systems, because of their diversity (more than 50000 species identified), and their exceptional growth rate (Jensen, 1993). Some species contain up to 70% of cellulose, and almost zero lignin, characteristics that make algal materials easier to process and more sustainable than other bio-based materials. Moreover, algae are extremely tolerant organisms, adaptive to various environmental conditions, allowing their growth practically anywhere. Algae can be processed to extract biofuels, electricity, cellulose, alginates (useful as binding agent) and other materials with many potential applications (Wijffels, Kruse & Hellingwerf, 2013).

Algal materials, including biofuels and natural pigments, can be derived either from micro- or macro-algae. In the case of micro-algae, the production starts from harvesting the micro-organisms, but for macro-algae, materials are produced by first drying the algae and then processing them with various techniques. For example, designers have developed techniques to extract algal sub-components from dried algae, such as gelatinous substances, pigments or other alginates. The use of macro-algae, being a process of re-purposing rather than that of growth of an organism, seems to slightly differ from what we defined as Growing Design. However, we argue that designers still actively cooperate with algae, because they re-configure the biological components of the organism to fabricate new materials. Doing so, designers need to develop an in-depth understanding of the biology of the organism employed, without which they would not be able to fabricate new materials. Furthermore, we suggest that the diverse biology of algae still presents a whole set of unexplored opportunities to Growing Designers. Microalgae, for example, have a large potential for the production of cellulose-based materials, along with other interesting abilities such as the generation of electricity (Hannon, Gimpel, Tran, Rasala, & Mayfield, 2010). Yet, the lack of an effective indoor system of harvesting algae limits their potential use in biotechnology and in product design. Since several researchers are addressing this topic (Talukder, Das & Wu, 2014), it is possible to speculate that in the near future, designers will be able to exploit the full potential of algae for Growing Design.

Similar to the other materials fabricated by Growing Designers, algal materials are also highly influenced in their properties by the strain of organism employed and by the fabrication process adopted. Depending on these variables, it is possible to achieve almost any typology of materials, from foam and bio-cement to inks and textiles. Hence, the potential of algae lies in this vast range of possibilities they entail, as much as for the high quality of the materials produced.

De Algarum Natura – By Officina Corpuscoli

In this project, Maurizio Montalti (Officina Corpuscoli, already mentioned in this paper for his work on fungal materials) engaged in the fabrication of materials from seaweed, triggered by its vast accumulation in marine environments (Montalti, 2015). In collaboration with the company Huiberts/Danvos BV, he developed fully biodegradable materials, whose properties range from hard to flexible and from translucent to opaque (Figure 6). The intention behind the project was to make effective use of seaweed waste produced by the company, which uses algae as fertilizer for their production chain. In order to utilize the waste stream, the designer developed a technique to extract agar-agar and carrageenan components of algae that are used to fabricate the material. These components are then recombined with the fibrous leftovers of the company's production cycle to form 2D flat materials, that can then be processed to form 3D shapes.

Fig 6. "De Algarum Natura" – a palette of materials derived from seaweed.

Agar plasticity – By AMAM group

The group of Japanese designers are conducting a research project to use agar to replace synthetic plastics (Araki, Maetani & Muraoka, 2015). Agar is extensively sold by the Japanese food industry in the form of blocks, whose light, feathery qualities inspired the designers to investigate its potential as packaging material. They developed three techniques to fabricate materials from agar using either pure agar powder or recombining it with red algae fibres. By experimenting with different concentrations of agar and algae, designers were able to obtain several types of materials having varying hardness and thickness. Figure 7 shows the fully biodegradable materials achieved by the AMAM studio, ranging from a clay-like composite to cushioned packaging for plant pots and wine bottles. The AMAM group is now establishing industrial partnerships in order to find support to develop the materials further.

Fig 7. “Agar Plasticity” – development of a set of materials grown from algae, ranging from foam-like to cement-like materials.

Discussion

The descriptions of the various cases of Growing Design identify few shared characteristics of the materials grown from living organisms. A clear advantage that these materials bring is higher **sustainability**. Mycelium, bacteria and algae are almost inexhaustible organisms, as they are widely distributed around the world and are fully renewable. Being fully compostable and biodegradable, they can be sustainable alternatives for disposable products. Another advantage is the **efficiency** of the production methods. Growing Materials are produced from the growth and reproduction of living organisms, which occur at impressive rates. The efficiency of this system becomes apparent if we compare it with our conventional system of producing artefacts from raw matters which took centuries, if not ages, to form. With the current rate of deforestation worldwide, even wood fails to qualify as renewable resource. Organisms such as mycelium, algae, and bacteria are instead easily reproducible and are abundantly formed in terrestrial and marine ecosystems, thus promising a far more sustainaible source of materials. In Figure 8 we present a timeline that highlights the striking differences in the production of fungal, bacterial and algal materials when compared to wood and fossil-based plastics.

The very fact that the materials are grown – i.e. **grow-ability** of the material– opens up new possibilities for design. For example, such materials can be grown directly into a shape, symbiotically producing the material and the product together. Other cases demonstrate that their grow-ability can be used to skip binding processes of different parts, by triggering growth of the organism such as to join the edges seamlessly (Lee, 2011). Connected to this characteristic is another important dimension of Growing Materials: the **time** necessary for the organisms to fabricate the matter. They grow over time, and when the growing process is completed (i.e. when the product is ready), they still continue to change and **adapt** over time. Conventionally, designers are used to interact with materials as a means to craft their ideas, making them tangible (Manzini, 1986). They tinker with material and reflect upon the outcome of their experiments in a learning-by-doing cycle. Instead, Growing Design involves a delay in time of few weeks, temporally separating the moment of crafting from the evaluation of the outcome.

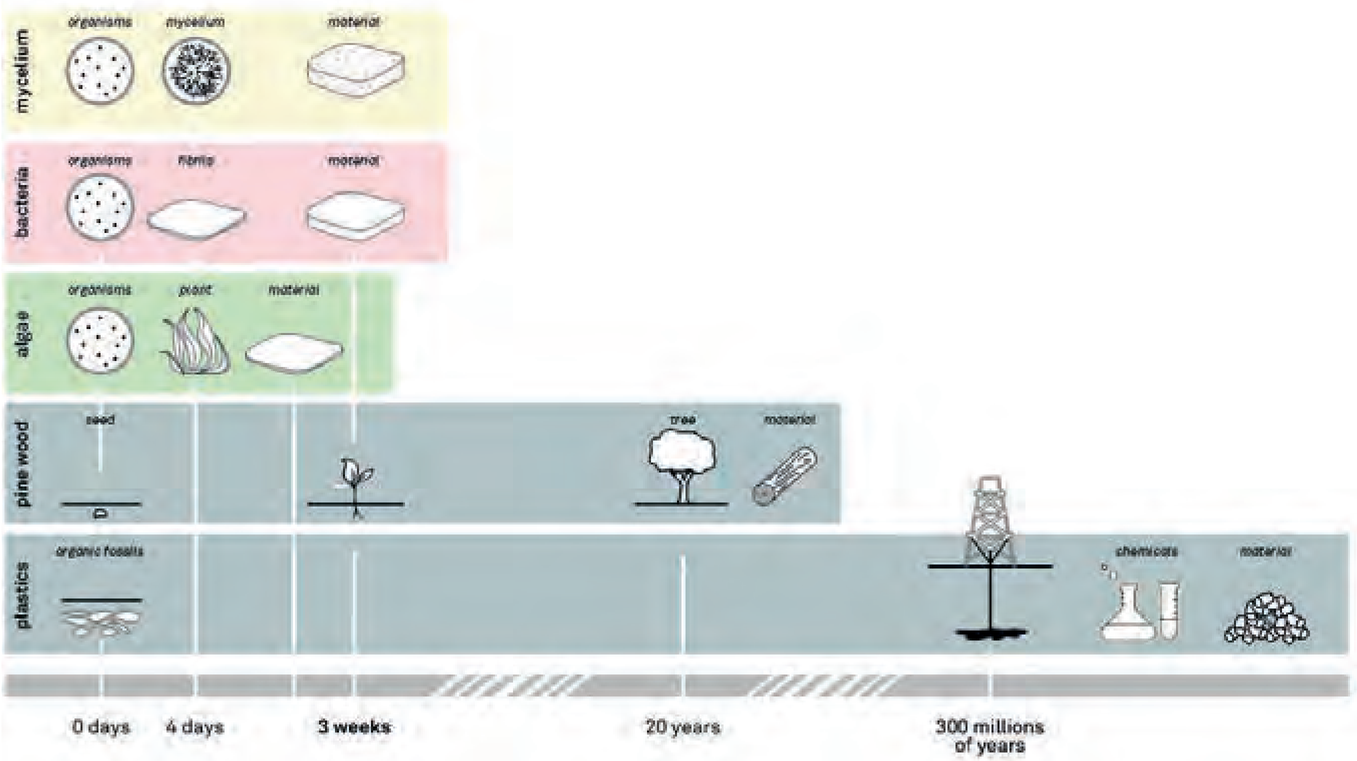

Fig 8. Comparing the timescale of industrial manufacturing with Growing Materials (top three) and more conventional materials used in product design.

Besides time, Growing Design also radically changes the **scale** at which designers work with materials. While designers typically relate to materials at the scale of millimeters, in this emerging practice they descend to the microscopic scale, entering a domain traditionally assigned to material scientists (Miodownik, 2007). This offers Growing Designers the possibility to control the material composition, fine-tuning its qualities through the variables of their fabricating process. The cases provided in the paper enable us to outline the variables shared by Growing Materials (Figure 9). These are the variables that Growing Designers can manipulate to achieve their intended results of the controlled fabrication process. Being concerned not only with the technical performances of an artifact, but rather with its social significance, designers can use these elements to consider how people will receive the material, and achieve their goal in terms of experiential qualities (Karana, Barati, Rognoli & Zeeuw Van Der Laan, 2015).

As we have seen from the cases presented, Growing Designers do not usually focus on the development of *one* material– but rather of *a palette* of materials. Growing Designers are somehow redefining the concept of ‘natural’, as they are able to control the matter and achieve variants of natural materials. For this reason, we argue that Growing Design changes the way we relate to Nature. Moreover, designers who grow materials set up the fabrication process and then let the living organisms take the role of creators/makers. The organisms collaborate as active and sentient agents of the creative process, offering their intelligence and productive abilities. At the same time, the growth of these organisms is guided and driven by humans, who provide a specific environment for it. This symbiotic relationship identifies the **collaborative process** in which designers and Nature mutually benefit from each other. Growing Designers forge the conditions for the invention of new matter, which would not exist otherwise. Take the example of mycelium-based composites: mycelium would certainly grow into sawdust, forming mushrooms or decomposing waste, but it would not transform itself into a bulk material that has no ecological purpose – rather than man-made ones. In Growing Design, Nature is triggered by the human intervention for the production of man-designed, yet ‘natural’, materials.

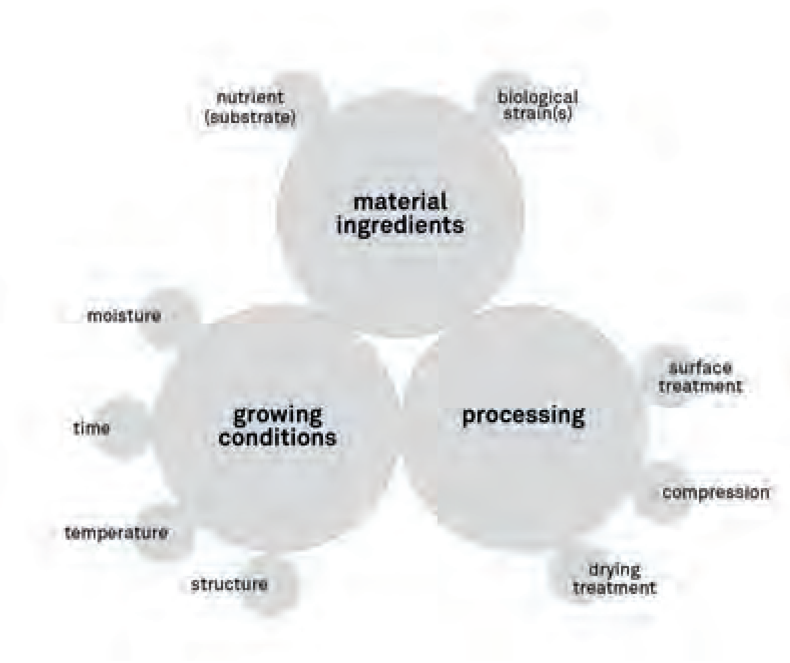

Fig 9. The variables designers can manipulate in Growing Design, to affect the final result in material qualities (adapted from Blauwhoff, 2016).

Conclusions

This paper contributes to a fundamental definition of an emerging material design practice: Growing Design, which involves fabricating materials from living organisms. We positioned this practice among other related approaches at the intersection of biology and design. Through this taxonomy, we identified six traits that manifestly characterize this emerging material practice, such as its roots in crafting and Do-it-yourself practices. Furthermore, expanding on the three classes of Growing Materials derived from fungi, bacteria and algae and presenting two design examples for each, we achieved an understanding of how these materials are fabricated. The subsequent discussion elucidates the unique opportunities of Growing Materials, such as the possibility to grow them directly into a shape (the grow-ability) and their growing time. In the near future, this emerging material practice will be confronted with challenges such as upscaling the fabrication methods to meet the requirements of industrial manufacturing. We see the necessity to understand the materials grown from microorganisms in a more systematic manner, both from the technical and the experiential perspective. As these materials are very novel to product design, there is limited knowledge on their technical properties and mechanical performances. Likewise, how people receive these materials hasn't been explored to date. Failing to explore the experiential properties of Growing Materials could engender a connotation with unfavorable aesthetic and cognitive associations (Karana, 2009). Instead, we see the potential in Growing Materials not just in acting as a surrogate to others (Rognoli et al., 2015), but also to be identified by their own, unique characteristics that can be expressed and embedded in appropriate designs. In this sense, understanding the growing materials from a technical and experiential perspective can be a true asset to the future development of Growing Design. In the upcoming project 'Mycelium-based materials for product design' (STW-project nr. 14572), we will be targeting this research agenda and the further development of mycelium-based materials for product design.

Acknowledgements

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Serena Camere

Serena Camere is Post-Doc researcher at Delft University of Technology. Serena concluded the PhD (cum laude) in March 2016 with a thesis titled “Experience (Virtual) Prototyping”, which explored the potential of new CAD/CAM technologies for experience-driven multisensory design. Within this research, she developed methods and tools for designers, to assist them during the use of these technologies for experience-driven design. After the PhD, her research evolved towards the Experiential Characterization of Materials, coupling her interest for materials with the experience-centered approach developed during the PhD. In the STW-funded project “Mycelium-based materials for product design”, she is in charge of conducting a series of characterization studies (both on a technical and experiential level) to assess the material's properties. The results of these studies will be then used to stimulate the further development of the material and its embodiment in products. Serena has been constantly seeking for opportunities to merge design practice and design research. This has led her to contribute to peer-reviewed journals and international conferences, as long as to engage in several design contests and projects as a design professional, receiving distinctions and awards in both contexts (Lucky Strike Talented Design Award 2013; Best Paper Award at Design & Emotion 2016). In the past, Serena has collaborated with design studios and design companies, such as Skitch, Serralunga, Alessi, Woodnotes, Camparisoda, Eurochocolate, Design Innovation and Fiat-Chrysler.

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The Plastic Bakery: A Case of Material Driven Design

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Keywords
Materials Experience, Material Driven Design, Do-It-Yourself Materials, Recycling, Plastics

Abstract

A growing number of scholars argue that understanding how people experience materials in products, i.e. Materials Experience, is essential in designing meaningful material applications. Material Driven Design (MDD) has been developed as the method to understand these experiential traits of materials and embed them in the design process. However, the MDD method is yet to find its way as a mainstream design practice across diverse projects. This paper presents one of these projects, in which a designer followed the MDD method to design (1) a service system for collection and recycling of plastic wastes, and (2) a product that brings forward the unique qualities of recycled plastics and make people cherish re-cycled plastics as personal Do-It-Yourself souvenirs.

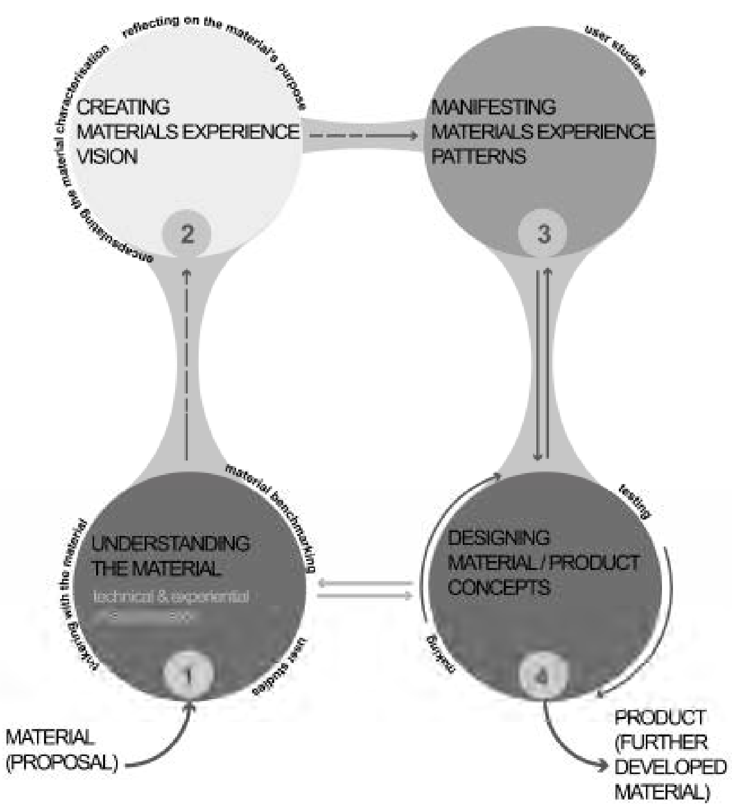
Introduction

In a global economy, where manufacturing companies compete neck to neck to cut costs and deliver higher product value, plastics have become ubiquitous. They are inexpensive, durable, lightweight and easily moldable into various products. From the moment we lift up a toothbrush in the morning till the moment we switch off our bedside lamps, we are surrounded by them. The British Plastics Federation (2008) estimates that around 4% of the world oil and gas production serves as raw materials for plastics and a further 3-4% provides energy for the manufacturing process. In 2014, the European Union alone produced 25.8 million tonnes of plastic wastes (PlasticsEurope, 2016). Most of such waste finally ends up in landfills or oceans becoming persistent organic pollutants in terrestrial and marine habitats

Hopewell, Dvorak and Kosier (2009) state that approximately 50% of the plastics are used for short-term disposable consumer items and packaging. In view of the growing need to curb plastic dumping, designers today attempt to design products that are meant for longer use or reuse, and packaging that uses eco-friendly materials or minimum plastics. Designers also attempt to minimize the number of components in packaging to facilitate separation of different kinds of plastics and easier recycling. However, recycling plastics is a process that is much easier said than accomplished. Reheating plastics progressively degrades the long polymer chains causing a reduction in strength and stiffness of the material (Möller, Strömberg and Karlsson, 2008). Companies that use plastics for their products, therefore, do not always prefer recycled plastics. Yet low technical performance is not the only reason behind the resistance of companies towards using recycled plastics. Designers, in general, dismiss recycled materials as inexpensive and inferior quality before exploring new applications with them (Dehn, 2014)

Introduced by Karana, Hekkert and Kandachar (2008), the notion of Materials Experience emphasizes the role of materials as simultaneously technical and experiential. Giaccardi and Karana (2015) introduce four levels of materials experience as: sensorial, interpretive, affective and performative. While the sensorial level describes how a material is perceived through our senses of touch, vision, smell, sound and taste, the interpretive level depicts the meanings we assign to materials. The affective level describes the emotions that are elicited by materials and the performative level speaks of the actions and performances that are established around the material object. We argue that if a designer can systematically explore the experiential qualities of recycled plastics and embed this thinking in the design process, he/she can reach to richer, more meaningful applications, which bring the unique qualities of the material forward.

In this paper, we present the journey of a designer (Ghazal, 2016) who followed the Material Driven Design (MDD) method (Karana, Barati, Rognoli and Zeeuw van der Laan, 2015) in the context of developing a product made of recycled plastics and a service system to support the collection and recycling of plastic wastes. The method provides a step-by-step approach from understanding a material to its final embodiment in a product. It guides the designer to envision and develop the material by bridging the gap between technical properties and experiential qualities through questions such as: “what it does, what it expresses to us, what it elicits from us, and what it makes us do” (Karana et al. 2015).



The MDD method developed by Karana et al. (2015) begins with a thorough understanding of the material from the technical perspective (through laboratory tests) and experiential perspective (though user studies). Material benchmarking confers the designer with knowledge of the current products in the market and activities with that material. The second step of the MDD process involves creating a vision of the experience that the designer wishes the user to have when the material is incorporated in a product. The third step comprises of understanding the perception of the material that exists in the society and the final step involves creating a meaningful product or product system that builds on the understanding of all technical and experienctial traits of the material as well as the existing material experience patterns.

The Design Assignment

We asked the designer to explore the experiential qualities of recycled plastics and design a Product Service System (PSS) which brings forward the unique qualities of the material and motivates people to recycle and collect plastics.

Step 1: Understanding the material

The designer decided to triangulate on Polyethylene as her working material since Polyethylene does not emit dangerous fumes while heating. She conducts several tinkering studies with the material to understand its properties, its behaviour under different production methods and the opportunities it presents.

Tinkering with Recycled Plastics

Painting

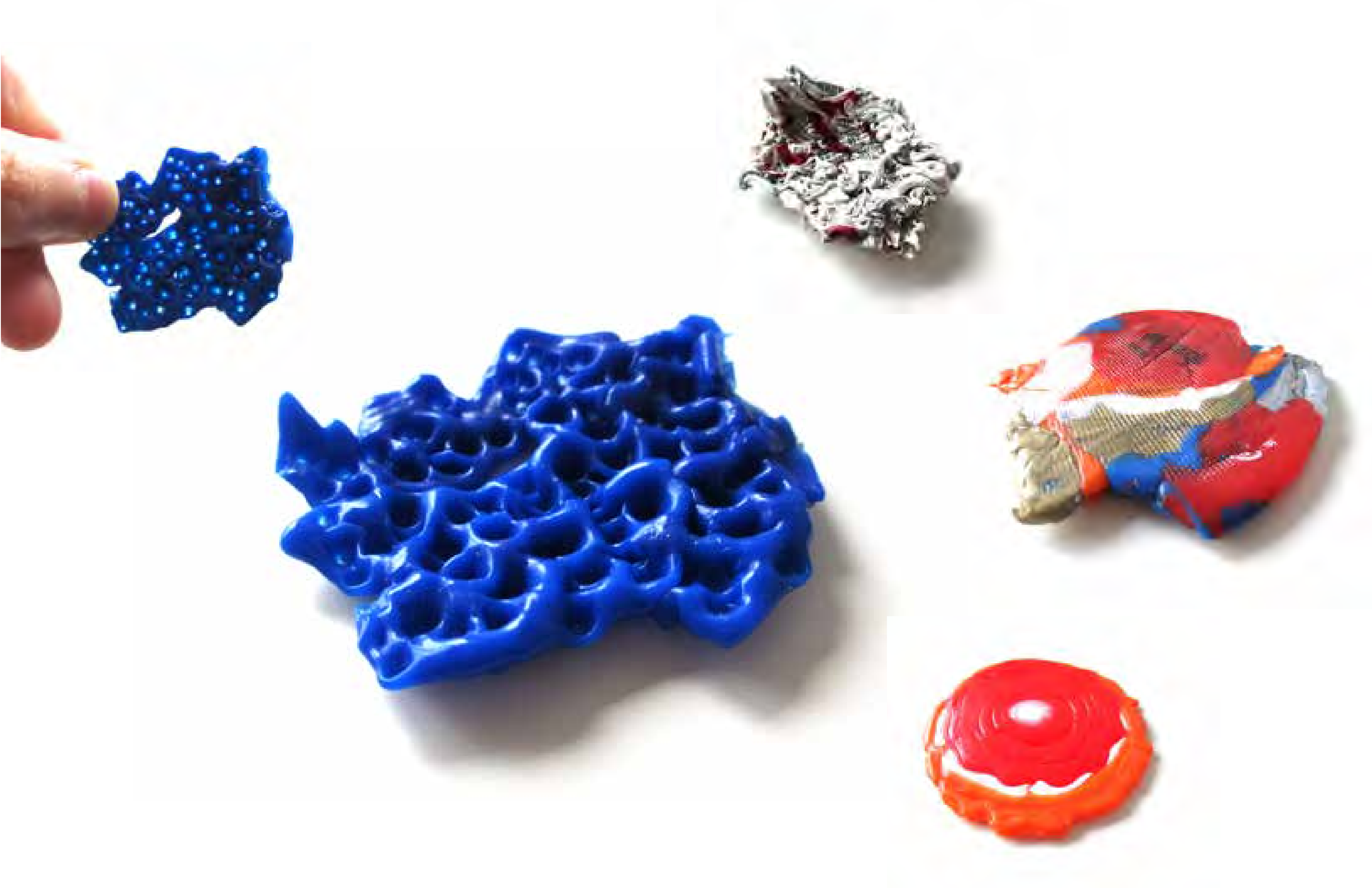
She painted on a canvas with molten plastic using a soldering iron. Beautiful “brush-strokes” could be created and the layered texture created depth in the paintings. But she reported a time constraint in making the strokes since the molten plastics congealed fast.

Plastic Wool

She created Plastic wool in the shredder but the process gave out plastic dust which is dangerous when inhaled.

Baking

She baked various combinations of coloured bottle caps in an oven at 180°C for 10 minutes. She then subjected it to cooling with air or water or pressing while cooling.

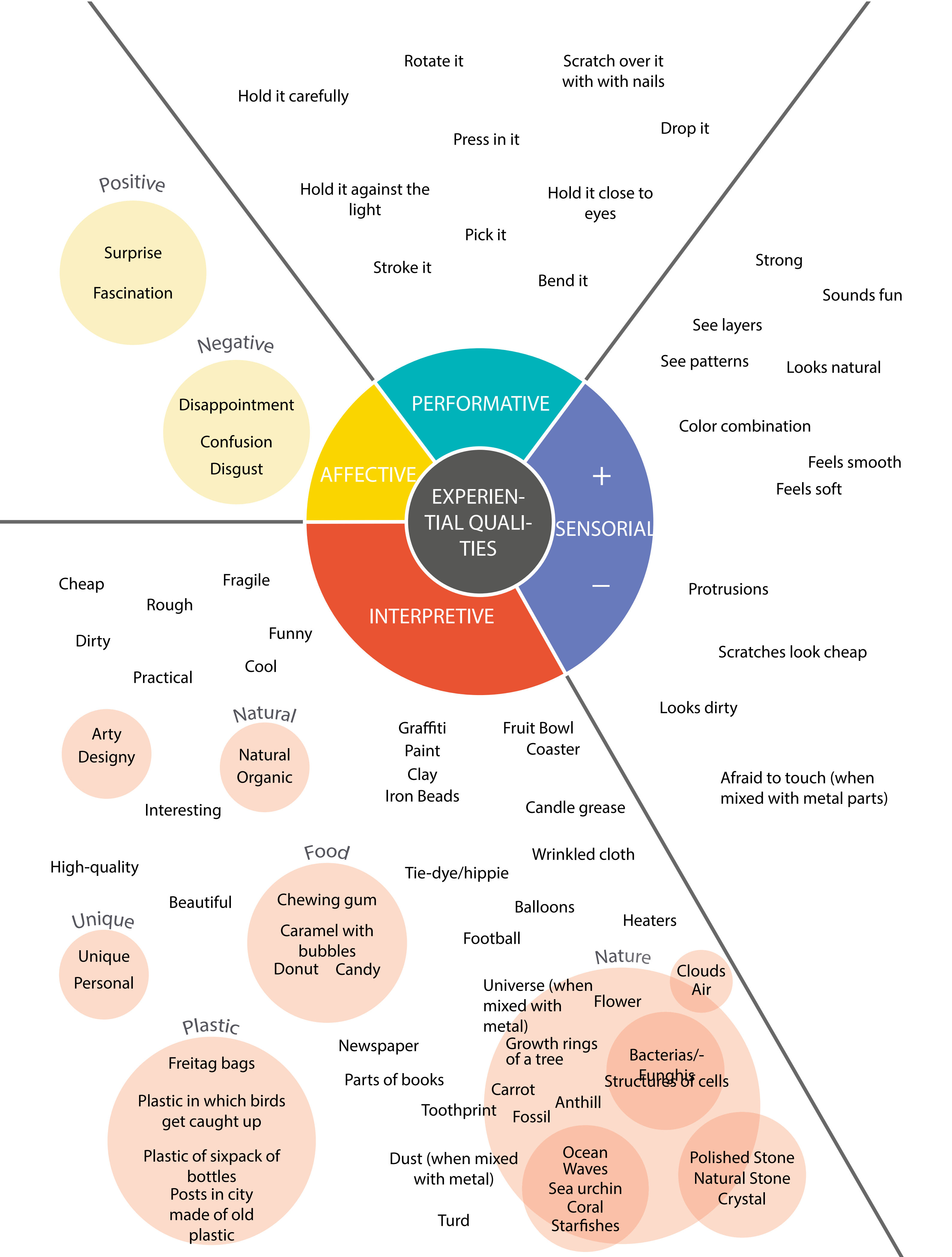


Plastic Blocks & Tiles

She finally created blocks and tiles with plastics. While the blocks could be give a very layered look, the thin plastic tiles presented a delicate translucent appearance. It was possible to knead the blocks with hands and give different shapes and to create imprints on the tiles with stamps.

Understanding Experiential Qualities of Polyethylene

As the MDD method suggests, understanding a material fully involves understanding its technical as well as experiential qualities and their interrelationships. The designer interviewed 12 students from the Masters program in TU Delft in an attempt to characterize polyethylene at the four experiential levels (sensorial, interpretive, affective and performative). In the interviews, she used the samples she had created through tinkering with the material. The participants expressed a range of emotions from pleasant surprise to disgust. They made interesting associations of the materials with objects found in nature such as wood, fossils, skies, sea-urchin, etc. They curiously held the sample close to their eyes, scratched it, stroked it and held it against light. The following chart shows a breakdown of the various reactions and emotions elicited in the participants when they were presented with the various material samples.

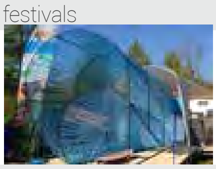


EXPERIEN-
TIAL QUALI-
TIES
PERFORMATIVE
AFFECTIVE
SENSORIAL
+
–
INTERPRETIVE
Hold it carefully
Rotate it
Scratch over it
with with nails
Press in it
Drop it
Hold it against the
light
Hold it close to
eyes
Pick it
Stroke it
Bend it
Positive
Surprise
Fascination
Negative
Disappointment
Confusion
Disgust
Strong
Sounds fun
See layers
See patterns
Looks natural
Color combination
Feels smooth
Feels soft
Protrusions
Scratches look cheap
Looks dirty
Afraid to touch (when
mixed with metal parts)
Cheap
Fragile
Rough
Dirty
Funny
Practical
Cool
Arty
Designy
Natural
Natural
Organic
Interesting
Graffiti
Paint
Clay
Iron Beads
Fruit Bowl
Coaster
Candle grease
High-quality
Food
Chewing gum
Caramel with
bubbles
Donut
Candy
Tie-dye/hippie
Wrinkled cloth
Beautiful
Unique
Unique
Personal
Balloons
Heaters
Football
Nature
Clouds
Air
Universe (when
mixed with
metal)
Flower
Plastic
Freitag bags
Plastic in which birds
get caught up
Plastic of sixpack of
bottles
Posts in city
made of old
plastic
Newspaper
Parts of books
Growth rings
of a tree
Bacterias/-
Funghis
Structures of cells
Carrot
Anthill
Toothprint
Fossil
Dust (when mixed
with metal)
Ocean
Waves
Sea urchin
Coral
Starfishes
Polished Stone
Natural Stone
Crystal
Turd

Material Benchmarking

The first step of MDD also recommends ‘material benchmarking’. The designer explored different products and production methods of goods in the market made from recycled plastics to find new material applications and experiential opportunities. She, specifically explored the unseen potential of the material. She categorized her findings with the aid of Material Benchmarking cards and tables. She found the idea of people collecting plastics in beach cleanup drives particularly interesting. She also sought inspiration from the product ideas that involved people through group Do-It-Youself activities and forstered community spirit.

MATERIAL BENCHMARK TABLE (MB) USE

APPLICATION PICTURE / SAMPLE				
NAME	Dopper	Washed ashore-sculptures	Melting pot table	XXXL Sakke
MANUFACTURER	Dopper	Washed Ashore	Dirk van der Kooij	Leonie&Lois
COMPOSITION	PP, ABS, TPE - Not recycled.	Marine Debris	Different types of plastic	PP - Packaging straps
RAW STATE PICTURE / SAMPLE				
TECHNICAL PROPERTIES	Strong, Waterproof, Hygienic.	Different colors, textures.	Strong, waterproof, colorful	Appropriate for weaving, colors, textures.
EXPERIENTIAL QUALITIES	Transparent & non-transparent. Funny shapes (cap). Tilt cup and use it as a glass.	Depth by trash, detailed., arty.	Color patterns flowing into each other, attractive appearance, curiosity, unique.	Interesting textures.
APPLICATIONS	Bottles Wave of bottles for festivals	Art objects	Table	Clutches, wallets, laptop sleeves, bags.
ACTIVITIES		Exhibitions.	Tables for bars/ restaurants.	Packaging (for money/ laptop/belongings)
ULTIMATE PURPOSE	Decrease single-use plastic, increase awareness of single-use plastic.	Educating and creating awareness about marine debris and plastic pollution through art.	Show the beauty and uniqueness of recycled plastic materials.	Show African culture, reuse plastic waste.

MDD Table (Karana et al.,2015)

STEP 2. Materials Experience Vision

The designer reflected on the results of her tinkering experiments with recycled plastics, her understanding of its experiential qualities and her findings from the material benchmarking. The element of surprise that the participants expressed at the colour patterns arising from the flow of plastics and the translucency of the tiles captured her interest. However, she felt that the emotion of surprise was heightened for her owing to her involvement in the whole process from melting the plastics to seeing the beautiful striated patterns in the final form. She retained the idea of passage of light through the material and envisioned a product wherein this feeling of “creating beauty” is infused. When the surface was imprinted with a stamp and the pattern and the irregularities of handcrafting became visible when the sample was held against light, it further added to the feeling of surprise.

In conceptualizing her PSS, she reckoned that “making” is a fun experience. From her personal experience, the final product was very gratifying since she was part of the “baking” activity and saw the process unfold right from heating the plastics to molding them in various shapes which can be even more enjoyable when conducted in a group. The design of the “First Supper” - An Extraordinary Dinner (2008) by Berlin based designer, Jerszy Seymour illucidates how people came together and built the bench by melting plastics which lead to a richer experience for the product user.

“When the users witness plastic wastes transform into beautiful products, it makes them aware of the possibilities and value of waste and also motivates them to collect it.”

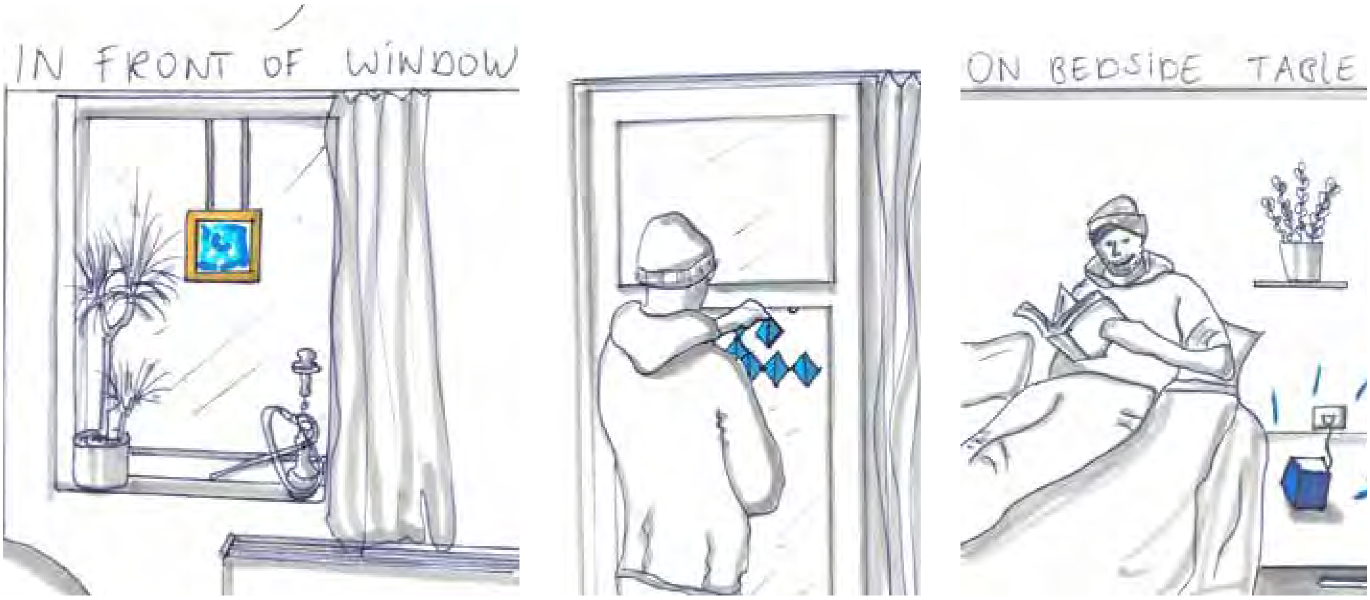
- Designer, after engaging people.

STEP 3. Manifesting Material Experience Patterns

The third step of the MDD method focuses on understanding the patterns that exist in the society concerning how certain materials are experienced in particular ways. The designer however focused on understanding how people experience baking instead of the material-people relationships. She conducted an online survey and asked the respondents if they liked baking and the reasons behind their liking or disliking it. Keywords were collected and charted on a mindmap. The responses manifested a perception of baking as an activity that is relaxing and leaves room for expression. This result further inspired the designer toward her final PSS concept.

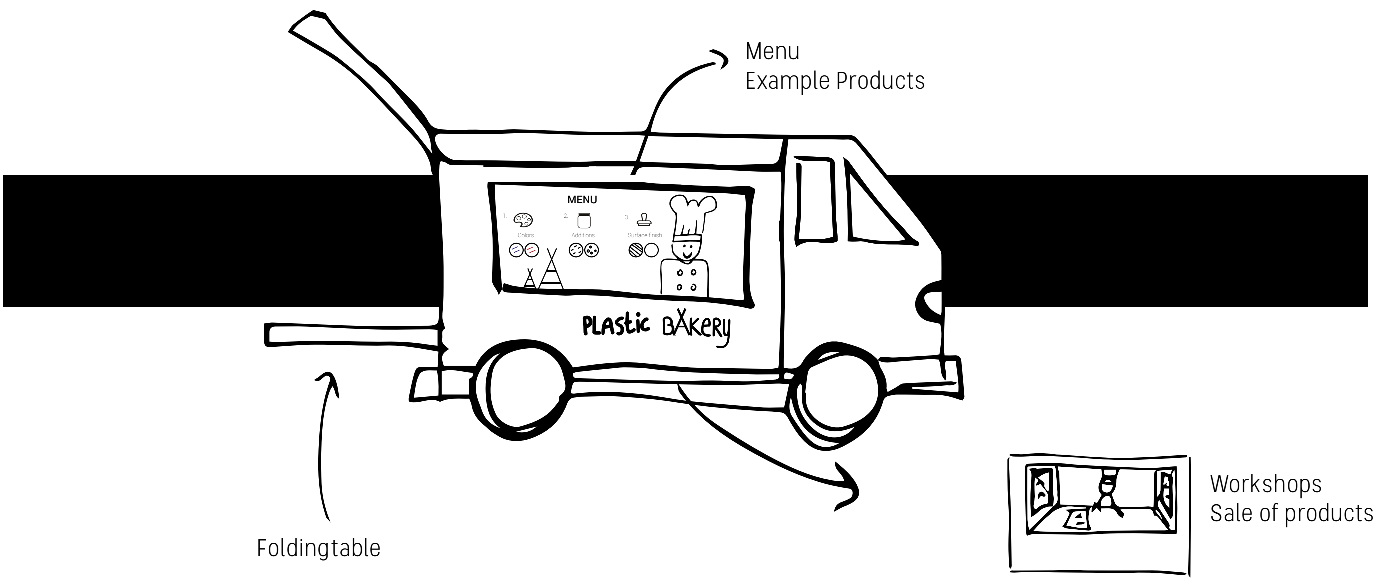
STEP 4. Conceptualizing a PSS: The Plastic Bakery

The project, creatively named as the “Plastic Bakery” (Ghazal, 2016), aimed at converting plastic waste into do-it-yourself items of craft. The design phase was split into design for material application and design for services around the material.



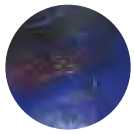
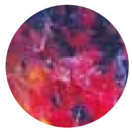
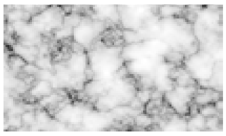
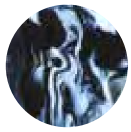
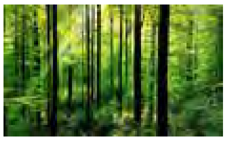
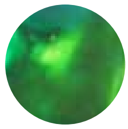
Product
Through concept drawings, the designer arrived at three product concepts that utilized the passage of light through a thin plastic tile- “Nature in a frame”, a “window curtain” and a “bedside lamp”. She made rough prototypes of the three concepts, but eventually converged on the bedside lamp as it evoked the best imagery of nature.

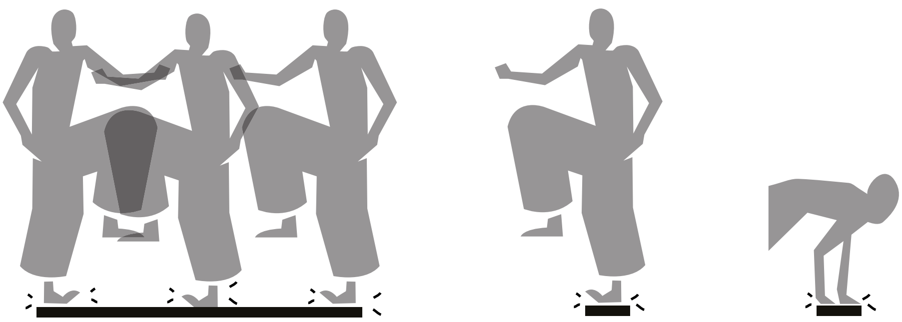
Service
Collecting the waste raw materials for the product was a crucial part of the making process since it made the people feel like they built the product from scratch and have a greater sense of belonging for it. She also ideated that the baking of the plastic wastes can be organized as a group activity to make it more enjoyable. She assigned it a very creative name: “The Plastic Bakery.” Here the “baking” analogy not just alludes to the similarity of processes, but also to the feeling of satisfaction from shaping the material with one’s own hands. Having the whole process done as a community activity promotes social cohesiveness and leads to higher social sustainability of the PSS (Vezzoli et al. 2014).



The designer set up a "Plastic Bakery" truck with tools, products and a "menu" of different motifs for the lamps. It was essential to encompass the satisfaction of having the whole process in their hands- from choosing the bottle caps for the chosen motif, melting and moulding the plastics and giving it final shape.

She also fabricated several wooden stamps with logos. The participants could press the molten plastics either with their hands or feet. Inspiration was drawn from the community activity of stomping on grapes to make wine. Some participants were so involved that they even improvised their own sprinkles for their lamps. When the final PSS was put to test, people enjoyed the whole experience from chosing the motifs to baking and fabricating their own lamps.

Elements	Bottle caps (Amount of caps per mold)	Impression	Examples
Air	2 2 2 1	 Cozy Clouds	 Cozy Clouds
Air	1 1 3 2	 Starry Sky	 Starry Sky
Water	1 3 2 1	 Cool Ocean	 Cool Ocean
Fire	2 2 2 1	 Warming Flames	 Warming Flames
Earth	3 1 1 2	 Magic Marble	 Magic Marble
Earth	2 2 2 1	 Funky Forest	 Funky Forest



The products were exhibited on the Future Materials exhibition at TU Delft. The display succeeded in exciting people and making them wonder if they could make it themselves.

Conclusions

The process of developing a PSS through the lens of Material Driven Design can unfold unanticipated and surprising avenues for capturing the interest of people. While designers predominantly focus on the experience of people with products, MDD offers a new methodological approach to consider the lesser known experiential aspects with materials in designing products. The designer of the Plastic Bakery discovered several unexplored experiential traits of plastics that guideed her in transforming a waste material into a product of personal delight. She designed a product that people can conceive and make themselves and cherish as a souvenir of their creativity. The designer reached the conclusion that active participation of the makers will add a whole new dimension to her PSS. Her constant tinkering and reflective approach aids her in developing a product which mobilizes the performative qualities of recycled plastics such as holding it against light.

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Prarthana Majumdar

Prarthana Majumdar is a PhD candidate in the department of Design Engineering at Delft University of Technology, the Netherlands. She graduated as a Mechanical Engineer from Indian Institute of Technology Guwahati (IIT) and later received her Masters from Stanford University, USA. Her current project, as a PhD scholar, focuses on promoting Do-it-Yourself material practices in the Base of the Pyramid, primarily India and Bangladesh. She focuses on Social Innovation and Materials Experience to understand how local eco-materials and recycled materials can be used more in such developing countries. The project aims at democratization of innovation and manufacturing in this segment that constitutes 70% of the global population.

Elvin Karana

Elvin Karana is Associate Professor of Design Engineering at the Delft University of Technology, where she founded and directs the Materials Experience Lab. Her research aims to understand and enhance the relationships people have with the materials of products. She has undertaken this topic with a holistic approach, capitalizing on not only the technical properties of materials, but also meanings, emotions and actions materials in products elicit. She coined the term “materials experience” to describe this holistic view. She is the main editor of “Materials Experience: Fundamentals of Materials and Design”. The Material Driven Design method she developed is applied in design courses in major European universities.

Sabrin Ghazal

Sabrin Ghazal is recently graduated from the Master Design for Interaction at Delft University of Technology, the Netherlands. For her graduation she developed the Plastic Bakery, the design of a product and service around recycling plastic waste. Her aim was to show people the value of plastic waste, by surprising them with the beauty of the material. She explored the material qualities of plastic bottle caps and found out that the material can look natural and that patterns can arise. Workshops were developed during which people can bake their own product and see the transformation of waste into a valuable material. She is currently turning her concept into a business.

Marieke H. Sonneveld

Marieke H. Sonneveld is an Assistant Professor at the Department of Industrial Design Engineering in Delft University of Technology. In addition, she was a design teacher for many years at the Design Academy Eindhoven. In both positions, her research and teachings focus on the meaning of touch in human-product experience. She developed a framework to unravel the tactual experience, in order for designers to be able to have access to it, to explore it, and to develop their sensitivity towards the aesthetics of the tactual experience. Developing sensitivity, becoming ’super feelers’, is crucial for designers to design meaningful tactual experiences.

Design from Recycling

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Abstract

The amount of materials that industrial design engineers can choose from to materialise their designs keeps increasing. However, emerging new materials such as recycled plastics often struggle to get adopted after their introduction to the competitive market. This paper elaborates on the first steps within an interdisciplinary research project between materials science and industrial design engineering regarding 'Design from Recycling' (DfromR) that aims to design specifically with both post-consumer and post-industrial mixed recycled plastics that are industrially processed through extrusion or injection moulding. The goal of this research paper is to search for a practical and methodological support for designing with the recycled plastic waste streams, which can be applied to the upcoming cases in the Design from Recycling project. Due to similarities with this ongoing research, the existing Material Driven Design (MDD) method is chosen as a reference method. However, to address the expected challenges regarding the specific context of industrial processing techniques, we propose and present two additional steps: (i) an elaborated technical characterisation in the engineering lab, leading to a virgin-recycled comparison table concerning the main technical material properties that need to be translated to designerly descriptions, and (ii) an user-centred consumer evaluation of the experiential material characteristics of the provided shape-independent samples, leading to experiential moodboards. To conclude, the paper presents the interpretation of the four steps in the MDD process in the context of the material cases of the ongoing Design from Recycling project.

Keywords

Design from Recycling; Mixed recycled plastics; Material Driven Design; Industrial design engineering; Materials experience

Materials as such have been extensively studied in science and engineering for years. As part of the growing product consumption and rapid technological development, increasingly more new materials emerge and are commercialised (Forester, 1988). This implies that, more and more of the traditional engineering materials are substituted by these ‘new materials’ (Rao, 2008) (e.g., bio-based materials, smart materials, recycled and/or recyclable materials). Hence, the available set of materials is rapidly growing both in type and number (Roth, Field, & Clark, 1994). Researchers estimated that there were over 80,000 technical materials in the world in 2010 (Jahan, Ismail, Sapuan, & Mustapha, 2010). Consequently, the amount of materials that industrial design engineers can choose from to materialise their designs, keeps increasing (Hasling, 2016). Since it no longer suffices to count on design experience with familiar materials, the selection and use of appropriate materials for a design becomes a lengthy, time-consuming and expensive process (Karana, Hekkert, & Kandachar, 2008a). Notwithstanding the fact that new materials gain more attention by designers in the past decade (Karana, Pedgley, Rognoli, & Korsunsky, 2016; Rognoli, Bianchini, Maffei, & Karana, 2015), often they still struggle to get adopted after their introduction to the competitive market (Maine, Probert, & Ashby, 2005). However, this evolution is insurmountable in the context of the current scarcity of raw materials, leading designers to (re)consider the entire lifecycle of their products to facilitate a circular and sustainable economy.

Context

This research paper is a part of the ongoing project “Design from Recycling”, an interdisciplinary collaboration between the University of Antwerp (Product Development) and the University of Ghent (Applied Materials Science). The purpose of this technology transfer (TETRA) project is to provide Flemish SMEs with the necessary knowledge and support to design and manufacture more and better products from recycled plastics, which should be considered as new high potential materials.

Design for Recycling is a fairly well-known strategy, where one focuses during the design process on the recyclability of products at their end of life. By contrast, **Design from Recycling** (DfromR) is a new approach within the concept of circular economy, which examines to what extent a new product can be produced from an existing flow of recycled polymers, and the design specifications this entails (Ragaert, 2016). Consequently, this project wants to provide an answer to the research question: “How do we design specifically with recycled plastics?”. The challenge lies not in the application of these recyclates in low-grade applications, but rather in high quality, sustainable products.

To date, material engineers are able to recycle and industrially process mixed plastic waste (Ragaert, 2015). Within this research project, the plastic waste is mechanically recycled, resulting in small flakes or pellets (Ragaert, 2016). Different groups of waste materials can be distinguished: either post-industrial or post-consumer, and varying between a single unpolluted polymer versus multiple, contaminated polymers (Hubo & Ragaert, 2014). The Design from Recycling project focuses on the industrial manufacturing techniques of extrusion and injection moulding, leading to the design and manufacturing of high quality consumer goods.

However, most stakeholders expressed (e.g. engineers, suppliers, manufacturers and designers) experiencing an impasse at the point of implementing these new materials in designs. By habit, they frequently try to simply substitute and mimic traditional materials in existing products, without considering the consequences, or without taking advantage of their unique identity and meaningful opportunities. Therefore, they often fail when introduced to the market as they are not socially and culturally accepted (Karana, Barati, Rognoli, & Zeeuw van der Laan, 2015; Manzini, 1986).

So, how can we differentiate recycled plastics on the market and towards consumers? Especially when the application of industrial processes such as extrusion and injection moulding reduces the recycled appearance and attitude of those materials. Should we emphasize this, or not at all? How can industrial design engineers influence the materials experience, i.e. “the experiences that people have with, and through, the materials of a product” (Karana et al., 2015; Karana, Hekkert, & Kandachar, 2008b)? This raises the question: how should we design with these mixed recycled plastic materials specifically?

Aim of the research

To facilitate the specific design process that has a mixed recycled plastic waste stream as the main starting point, we need a systematic guidance to support industrial design engineers (IDE) in this process. Accordingly, the goal of this research is to explore and define a practical and methodological support for designing with recycled plastics, that can be directly applied to the cases of the Design from Recycling project. In order to construct this set-up, three research questions were addressed in the following sections:

- What are the existing design approaches that could be applied to the cases of the Design from Recycling project? And consequently, which approach is most useful?
- What difficulties or limitations of the choses approach are expected during application? What adaptations might be needed to set-up this specific cases?
- How can the chosen approach be interpreted in the Design from Recycling cases?

Review on existing approaches

There is already a large body of research in the field of mechanical engineering, examining the material selection process from the viewpoint of materials science and engineering (Ashby, 2011). Only recently, attention shifted to the user-centred perspective of experiential characteristics and user-interaction (Hasling, 2016; Karana, 2009; Van Kesteren, 2008). To summarise, the different aspects of materials can be for the most part categorised in two groups, namely the engineering aspects and the experiential aspects (Hasling, 2016; Van Kesteren, Stappers, & de Bruijn, 2007). The technical aspects of materials define how the product will be manufactured and how it will function, whereas the experiential aspects are those that influence the usability, sensory appeal, experience, and personality of a product. (Giaccardi & Karana, 2015; Hasling, 2016). Obviously, to include all material considerations in a design process, also economic and ecological aspects have to be taken into account. However, the criticality lies precisely in the multidisciplinary combination of several material aspects and their interrelations. Hence, four main material considerations can be defined: technical properties, experiential characteristics, economic aspects, and ecological aspects. For the sake of completeness, social sustainability is currently not considered within material characterisation.

There is an extensive amount of tools or approaches from an engineering perspective, see Jahan et al. (2010) and previous research (Veelaert, Du Bois, Ragaert, Hubo, & Van Kets, 2016), but the Cambridge Engineering Selector (CES) Software of Granta Design (Granta, 2016) is probably the best-known. Their recent ‘Products, Materials and Processes’ database tries to bridge the gap between engineers and designers and is therefore included in this enumeration. However, it does not really provide a structured design approach to design with mixed recycled plastics as a starting point. Nevertheless, it can be useful to explore and visualise the technical properties in relation to other well-known and common materials.

From the IDE perspective, the following tools were selected. Van Kesteren et al. (2007) proposed the *Materials in Product Selection* (MiPS) tools consisting of a Picture, Sample, Question and Relation Tool to facilitate the materials selection process in terms of user-interaction and sensorial attributes. The *Expressive-Sensorial Atlas* by Rognoli (2004; 2010) focuses on experiential learning of material properties (Karana, Pedgley, & Rognoli, 2013) and wants to show the relation between sensorial attributes and a material’s perception by people. Karana et al. (2010; Karana, 2009) constructed the *Meanings of Materials* (MoM) model that explores the effect of expressive material characteristics on the meanings it will convey. Building on these foundations, Karana et al. (2015) introduced the *Material Driven Design* (MDD) method that structures a design process with a specific (new) material as the starting point, while bridging both the technical and the experiential perspective during four key activities.

Conclusions

In order to build upon existing knowledge and tools, the Material Driven Design (MDD) method was chosen as reference method due to its similarities with the Design from Recycling project that also puts a particular material – a mixed recycled plastic – as the basis for the design process. In addition, this approach also includes other existing tools - such as the MoM model - throughout its process.

However, according to our understanding, the challenge lies in the limitations of the industrial processing techniques (i.e. extrusion and injection moulding) that are used in our specific research project, which complicates manual tinkering with materials to explore them, as is currently done in the MDD cases with for example coffee waste (Karana et al., 2015) or mycelium-based composites (Parisi, Garcia, & Rognoli, 2016). Consequently, we propose two novelties to extend the current MDD method. First, we feel the need to further **elaborate on the technical characterisation** step (i) of this method and rework it to the context of our recycled materials and the more industrial environment and processing techniques. As a consequence of this industrial processing, the available material samples do not have a typical ecological or recycled appearance. Therefore, we want to accentuate the **end-user (consumer) evaluation** of the experiential characteristics of the materials exploration already in the beginning of the MDD process step (ii). In the following Section these additional steps will be explained.

Additional steps on a technical level

Relevant and critical materials considerations

Continuing on the elaborated technical characterisation possibilities from an engineering point of view, we need to know what to measure within this specific project context of Design from Recycling, in order to ultimately develop a comparison approach for recycled versus virgin plastics. To date, only limited knowledge is available on our new recycled plastic materials. In contrast to virgin materials, these mixed recycled plastics can derive from either post-industrial or post-consumer waste.

The initial research activity in this project addresses the search for a condensed list of the most relevant and critical material properties for all project partners (e.g. material engineers, industrial design engineers, processors and mould makers). Here, the goal is to identify the collection of materials data that is minimally required and that needs to be communicated between the stakeholders.

A first proposal was compiled during several conversations between experts from both material science and industrial design engineering (IDE) perspective, and then introduced to the members of the project's user committee. A reasoning with consequences approach was used to start identifying the differences between 'ability to measure' and 'need to measure'. The material scientists clarified what characteristics they usually measure, what standards they are used to fill in datasheets, and what their limitations are for measuring certain material characteristics, however focusing on properties that are needed for the injection moulding process. From the industrial design engineering perspective, a first reasoning was done explaining the specific characteristics they need to make design decisions and to select materials in the different phases of the design process. Matching these two perspectives is important to (i) eliminate unnecessary measurements (at the engineering lab), (ii) avoid missing information (that could lead to a non-use in the design practice), and (iii) build a common understanding to facilitate discussion and knowledge transfer. The concluding proposal is visualised in Figure 1.

technical				economic	ecological
mechanical	tensile strength	chemical	permeability	price	environmental impact
	flexural strength		water absorption	availability	recyclable?
	E-modulus		chemical resistance		biodegradable?
	flexural modulus		UV resistance		renewable source?
	yield point	thermal	service temperature (no load)		
	elongation (%) at break		service temperature (load)		
	creep resistance		thermal conductivity		
	notched impact strength		thermal expansion		
	hardness		glass temperature		
	fracture toughness	process-ing	viscosity		
physi-cal	density		mold shrinkage		
			processing techniques		

Fig 1. First proposal of technical, economic, ecological material properties within DfromR project.

Survey with IDE: method, participants, and results

The next step was to verify this list of chosen material characteristics with IDE in the field. Therefore, an online survey was conducted on the relevance and criticality of each of the material properties and characteristics over the three domains that are mentioned above (excluding experiential characteristics). For each material consideration category, respondents were asked whether a listed material property or characteristic was critical for them to know (for materials selection) throughout an average design process with plastics. Focus was not yet put on recycled plastics specifically since we argue that these materials should be presented and incorporated in the same and thus comparable manner as materials information on regular and well-known plastics, in order to facilitate the adoption of recyclates in the usual materials selection process. To rate the relevance of each property, respondents could choose between “yes”, “sometimes”, “no”, or “unfamiliar with the listed property”. At the end, respondents were free to add any properties that they missed in the list.

Through the alumni network of Product Development Department, fifty four respondents from design agencies, R&D departments and academia completed the online survey. The results were transferred to a datasheet and processed as listed below in Figure 2.

Fig 2. Results of the survey regarding the relevance of the proposed material properties.

To decide whether or not a material property could be omitted from the datasheet - from an industrial design engineering perspective - a critical threshold was set at both 50 percent and 80 percent. Consequently, all the material characteristics within 50 percent (“yes” and “sometimes” answers combined) are absolutely critical and are to be part of this project’s datasheet. To accommodate the broader information needs, only the material characteristics above 80 percent will be left behind in the continuation.

These results lead to the conclusion that the proposed data table is quite accurate, but that it is justified to omit the following material characteristics from the IDE’s viewpoint: elongation (%) at break, flexural modulus, glass temperature, and biodegradability. Consequently, this leaves us with a compact data table with the minimally required (relevant) material information that is necessary to proceed with the next project step: to design with these recycled plastics. As can be expected from IDE, especially the possible processing techniques, the price and availability of materials are an absolute must-know in the design process.

Extended technical research step

To conclude, the list of relevant material characteristics can be edited to a final version. At this point, the technical part of the table can be addressed. In order to practically use the obtained datasheet in the MDD method, this extended technical research step consists of three parts:

- Identification of missing material information that still needs to be measure, in contrast to information that can be reasoned ‘as virgin’ (A);
- Actual measurement of the technical data at the engineering lab according to standards (B);
- Interpretation and translation of the technical data into designerly descriptions (C).

A. Reasoning ‘as virgin’ - what to measure

Based upon the table of the desired technical material properties, further reasoning with consequences was done related to the technical characteristics. Material experts within the project were asked to - based on information of a previous research project about recycled mono polyolefins (Hubo & Ragaert, 2014) - make a comparison between virgin plastics and recycled plastics. During this focus group discussion, they had to indicate the manner of how each technical property of recycled plastics would differentiate from its virgin material (Figure 3). If, according to their experience, there was no relation between the virgin and the recycled plastic, the property should definitely be measured (third bullet coloured). However, ‘not equal’ does not necessarily indicate that the recycled property is worse, f.e. in the case of price and environmental impact. On the other hand, for those characteristics whose first bullet is coloured, a relationship could be determined (’as virgin’). For some characteristics, there was no doubt that the recyclates would act similar as the virgins, for others this only applies to post-industrial recyclates (second bullet coloured). This difference is due to the fact that post-consumer recyclates often had a long lifetime and their characteristics have changed due to UV radiation and pollution or contamination of other substances. However, these are global guidelines; the third bullet does not mean that the property can never be equal, but you cannot assume it is.

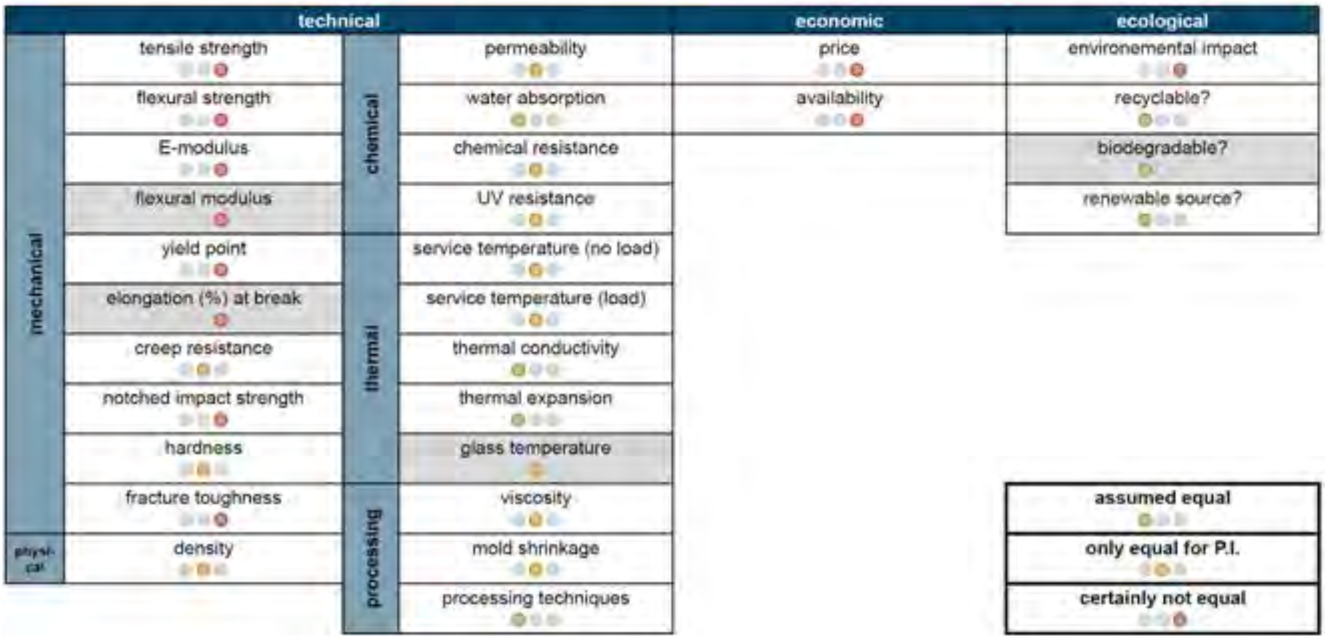

Fig 3. Table of technical, economic and ecological properties including the comparison of recycled plastics with virgins.

B. Measurement of the technical data according to standards

Once the missing technical information is identified – i.e. the information that cannot be assumed similar to the corresponding virgin plastics – standardised tests can be carried out in the engineering lab by means of test bars, both dog-bone and rectangular shaped, as visualised in Figure 4.

Fig 4. Test bars used for standardised testing, made from recycling flakes.

First of all, the composition of a specific batch of mixed recycled plastics (whether they are post-industrial or post-consumer) must be determined, together with the origin and potential contaminations such as coolant, paper, wood, metal, small amounts of other polymers, etc. Subsequently, different test were conducted within this research project, these are: Fourier-transform infrared spectroscopy (FTIR) to detect the type of polymers in the waste stream, mass-measurement method to define the melt flow index (MFI), a density kit to gravimetrically measure the density, differential scanning calorimetry (DSC) to obtain thermal properties, notched Charpy impact test leading to the impact resistance, a bending test to retrieve the flexural modulus, and finally a tensile test with an extensometer to calculate tensile strength and Young's modulus. More detailed information about the technical tests are not part of this paper's scope, instead the authors refer to earlier work (Hubo & Ragaert, 2014; Van Kets, Van Damme, Delva, & Ragaert, 2016). To conclude, the results and data can be transferred to the technical datasheet of each material.

C. Translation to designerly descriptions

The designer's approach or 'language' is characterised by fuzzy labels and descriptions. Consequently, the numerical data is not sufficient for IDE to start their design process with. We argue that the technical properties should be further explored and translated into designerly descriptions that they can work with during the MDD step of technical characterisation. We propose this can be done through an elaborated **technical translation** in order to formulate the implications, opportunities and limitations for the design process. This implies that the industrial design engineer will look for familiar and well-known materials that they already have experience with. Similar characteristics will be formulated as 'recycled material x sounds like known material y', or 'the strength of recycled material x is comparable to virgin material y'.

Additional steps on a user-centred level

After completing the technical characterisation, the recycled material will be explored from a user-centred perspective. To respond to the designer's approach – that is indispensable for designing material experiences – a set of different **samples** of this material has to be passed to the industrial design engineer, along with equivalent samples of well-known plastic materials to compare with. However, these samples should be **shape-independent** in order to exclude associations to similar shaped products. Therefore, we will use the test samples from the engineering lab (flat test bars), supplemented with the sprues that show differences in surface finishes of the mould.

In the case of the recycled plastics of this project, their technical material properties are still situated within the limits of most plastic materials that designers are familiar with. Hence, we argue that the *Experiential Characterisation* is a very crucial step for IDE to differentiate the recycled material on the market. Especially in the context of recycled plastics (that are mostly deriving from consumer waste), their perception by **end users or consumers** is considered as a bottleneck, and should therefore be explored early in the MDD process. This dualistic approach makes it possible to compare and incorporate the vision of both designers and consumers. To facilitate this process, we provided two formats for a first sensorial and interpretive exploration, building upon the sensorial Likert-scales of Karana et al. (Karana, Hekkert, & Kandachar, 2010) and comparable to the creation of personas. These input forms serve to break the ice, engage consumers and to introduce potential material descriptions that can be further discussed in interviews.

In addition, we want to encourage designers to compose supporting **Experiential Moodboards** for communication and inspiration. These inspirational moodboards can visualise a combination of both observed or intended material experiences that can be interesting in the idea generation.

Applying the MDD

With the two discussed adaptations in mind, the next Section will explain the set-up for the expected application of each step of the Material Driven Design (MDD) approach to future cases within the Design from Recycling project. As this project aims to design with and for relatively unknown or new, yet fully developed recycled plastic materials, it can be positioned in the second scenario as distinguished by Karana et al. (2015). As mentioned in the problem definition, the materials within our research project are not yet linked to settled meanings, user experiences or application areas, thus offering designers great freedom to introduce new material identities.

MDD Method Step 1 – Understanding the material: Technical and Experiential Characterisation

The MDD approach is initiated by the collaborating engineering lab that provides the technical datasheets and samples for the designers. Then, three simultaneous steps are performed in order to fully understand the given recycled plastic and to explore its unique opportunities. The *Technical Characterisation* will be continued by the designers through tinkering with the provided material samples in order to interpret the numerical data that is proposed by the engineering lab. In contrast to the previous, controlled conditions, designers are now encouraged to drill, bend, pull, break, and play with the materials themselves. Due to the specific context of industrial processing techniques, mould making and high processing temperatures, tinkering is limited to the material samples only. Despite the fact that this research project initiated from the application of extrusion and injection moulding, we would still encourage designers to look beyond this restriction and explore other industrial processes as well, such as rotation moulding, structure foam moulding etc.

Furthermore, we propose to visualise the main technical properties in reference tables and graphs in order to find links with other well-known materials and their application areas, leading to the interpretation of the general, practical significance of each property and thus, give meaning to the numbers. For example, a low E-modulus implies that the material is flexible and – in the case of polypropylene – is therefore typically used in integral hinges. Likewise, the combination of two properties such as cheap and light can position recycled plastics near materials such as concrete or cork, leading to new application fields. Finally, this exploration should lead to insights concerning the questions in Figure 5.

Technical characterisation of the material (TCM)	
Q1	What are the main technical properties of the material?
Q2	What are the most convenient manufacturing processes to form the material?
Q3	What about other manufacturing processes? How does the material behave when subjected to other processes?
Q4	What are the technical constraints of the material?
Q5	What are the technical opportunities of the material?

Fig 5. Guiding Questions for Technical characterisation (Karana et al., 2015).

However, when introducing the recycled plastics within this project as new and unique materials in the market, designers must first discover the experiential identity of each material, which can be done through the *Experiential Characterisation*. Giaccardi and Karana (2015; Karana et al., 2015, p. 41) state that “the designer should reflect on four different experiential levels: **sensorial**, **interpretive** (meanings), **affective** (emotions), and **performative** (actions, performances)”. Due to the industrial process limitation, designers cannot create samples themselves; our recycled plastics are no DIY materials (Rognoli et al., 2015). Hence, varying in aesthetic qualities is rather limited to shape and mould finish in this case. However, we suggest that they use the moulded sample set of the engineering lab to explore how it is being received not only by designers but also by end users or consumers, using the proposed sensorial and interpretive exploration scales. Through focus groups and interviews the material samples can be further discussed to dig deeper in the matter and find other meanings, emotions and actions, specifically within a recycled/sustainable context. Are the materials actually perceived as recycled plastics? Are they even associated with other recycled materials? This exploration should answer the questions in Figure 6 and its outcome can be brought together in several Experiential Moodboards (Figure 7).

Experiential characterisation of the material (ECM)	
Q1	What are the unique sensorial qualities of the material?
Q2	What are the most and the least pleasing sensorial qualities of the material (according to end users)?
Q3	Is the material associated with any other material due to its similar aesthetics?
Q4	How do people describe this material? What kind of meanings does it evoke?
Q5	Does it elicit any particular emotions – such as surprise, love, hate, feat, relaxation, etc.?
Q6	How do people interact and behave with the material?

Fig 6. Guiding questions for Experiential characterisation (Karana et al., 2015)

In the case of this research project, several pre-settled meanings were detected in a preliminary exploration such as the imperfections in the materials that express uniqueness and surprise, rather than an ecological impression. Another peculiar aspect is the lack of freedom regarding possible colours of the mixed recycled materials, which are usually black or dark grey due to the mix of all kinds of colours.

Fig 7. Experiential Moodboards exploring the possibilities of ‘black’.

As previously mentioned in the existing approaches Section, the Relation Tool by Van Kesteren (2008) can also be useful in this phase of the MDD process. In this way, the main sensorial attributes can be linked with various technical properties. This implies that designers can explore what sensorial attributes can still be modified up to a certain level later on in the design process to better fit the intended material experiences (e.g., the glossiness or surface texture partly depends on the mould finish).

Finally, insights through both the technical and experiential characterisations can be linked through the step of *Material Benchmarking* that concerns the questions of Figure 8. In this step, designers have to search for similar materials with regard to look, emerging experiences and sensorial effects of processing techniques in order to summarise their areas of application. The conclusions concerning the questions in Table X can be presented by means of diagrams and/or additional moodboards.

As our project’s materials are waste-based, other waste materials and their applications can be explored and correlation might be found in terms of imperfections, limitation of black colour, etc. In addition trends and strategies concerning waste recycling, circular economy or life cycle thinking can be mapped as well.

Material benchmarking (MB)	
Q1	What are the applications for which the materials have been applied so far?
Q2	What kind of activities do these applications support and why?
Q3	What kind of technical properties do others emphasize?
Q4	What kind of experiential qualities do others emphasize?
Q5	Is there any specific design approach, strategy, business model, or trend the material is bond to?

Fig 8. Guiding questions for Material benchmarking (Karana et al., 2015)

MDD Method step 2 – Creating Materials Experience Vision

Based upon the output of the technical and experiential explorations, the design intention can now be articulated in a ‘**Materials Experience Vision’** as stated by Karana et al. (2015). This statement should answer the questions in Figure 9, and it can be formulated as ‘the material - does what - with whom - to achieve?’. To compose this tagline, a final decision should be made on whether a settled meaning will be preserved or a novel meaning will be exploited in a future product. Consequently, it can be considered as the unique selling proposition that designers will use as their inspirational backbone to reflect on the material’s purpose throughout the further design process and idea generation.

Materials experience vision	
Q1	What are its unique technical/experiential qualities to be emphasized in the final application?
Q2	In which contexts would the material make a positive difference?
Q3	How would people interact with the material within a particular context?
Q4	What would the material's unique contribution be?
Q5	How would it be sensed and interpreted (sensorial & interpretive levels)?
Q6	What would it elicit from people (affective level)?
Q7	What would it make people do (performative level)?
Q8	What would be the material's role in a broader context (i.e., society, planet)?

Fig 9. Guiding questions for Materials experience vision (Karana et al., 2015)

Within the specific cases of this project, two opposite design strategies can be chosen to support the Materials Experience Vision. On the one hand the recycled character of the materials can be displayed and enhanced - c.f. the value of imperfection (Salvia, Ostuzzi, Rognoli, & Levi, 2011) - on the other hand the quality of the industrial possibilities (as similar to virgins) can be reinforced, without emphasising the recycling background.

MDD Method step 3 – Manifesting Materials Experience Patterns

In the third step, Karana stated that designers should extract two or more key meanings from their Materials Experience Vision and explore the link with formal properties (i.e. shape and processing techniques) through brainstorming sessions and the Meaning Driven Materials Selection (MDMS) tool (Karana et al., 2010). For example, people might appraise materials as unique and robust due to imperfections or a speckled surface. We propose to rely on links and material examples that are already available in literature and previously conducted MDD projects. We would suggest to match this available information with the industrial context of our project, to reason with the formal properties.

MDD Method step 4 – Creating Material/Product Concepts

On the basis of the vision statement and the target group, various application areas can now be identified, leading to a brainstorm about possible future **material-product concepts**. Subsequently, the regular design process can again be followed, consisting of trade-off, concept development, and detailed engineering. As Karana et al. discuss (Karana et al., 2015), in Scenario two with a fully developed material, the designer can only manipulate or influence its sensorial qualities through different shapes and mould finishes for surface quality, texture and gloss. To ensure that the product concepts still attribute the intended meanings and experiences, the involvement of end users is again essential in this design phase. For the detailed engineering, feedback is needed from the engineering side about technical considerations and design guidelines arising from the defined processing techniques. In case of injection moulding with mixed recycled plastics, this may involve a greater wall thickness, more reinforced ribs, etc. In addition, 3D strength simulations with CAD software are useful to test the performance and mechanical strength before even producing the mould.

Discussion

This paper presents the first steps within the ongoing research project 'Design from Recycling', which aims to support engineers and designers to apply mixed recycled plastics in high quality products. However, the suggested MDD approach still needs to be tested, reworked and verified through an iterative process of cases, as will be conducted in the progress of this research project. In this respect, during the progress of the case we may encounter the need to carry out the third MDD step more extensively after all.

First explorations within the initiated material cases showed that there are definitely product applications possible for these recycled materials as long as industrial design engineers are cautious about the technical properties that lead to design restrictions. Consequently, these materials should rather be differentiated on the user-centred level of experiential characteristics. As mentioned before, the strategy of 'the value of imperfection' can be further explored in order to elicit unique material experiences.

In order to further emphasise the sensorial attributes and technical properties on the one hand, and the designerly translation of these technical properties on the other hand, a more extensive sample set would be desirable. Within this research project, an injection mould will be developed for a material 'determiner', physically showing the most important technical (and sensorial) aspects for designers, such as glossiness, stiffness, shrink cavities, minimal wall thickness, etc. This would result in a hands-on resource for designers to understand the recycled materials and one-on-one compare their qualities with known virgin plastics, beyond what is possible through traditional datasheets.

Conclusions

This paper aimed to clarify the setup of a methodological approach that would facilitate the design process with mixed recycled plastics as a starting point. 'Design from Recycling' (DfromR) is a new approach within the concept of circular economy, which examines to what extent a new product can be produced from an existing flow of recycled polymers, and the design specifications that this entails.

To date, the material engineers within this research project are at the point of being able to recycle and industrially process mixed plastic waste through extrusion and injection moulding. However, an impasse is experienced at the point of implementing these new materials in designs; they often fail when introduced to the competitive market. To address this issue, the authors explored the existing Material Driven Design (MDD) methodology that also puts a new materials as the starting point of a design process, and interpreted how its four steps can be applied to the specific material cases of the Design from Recycling project. Due to the context of industrial processing at the engineering lab, some challenges had to be accommodated throughout this reasoning process, both on a technical and a user-centred level.

The proposed adaptations include a condensed list of relevant materials properties for all project partners; a survey to verify their relevance for industrial design engineers; a comparison approach for recycled versus virgin plastics; an elaborated technical characterisation at the engineering lab by means of standardised tests; a technical translation to designerly descriptions; the development of shape-independent materials sample sets; an end-user (consumer) evaluation of the experiential material characteristics; and finally, experiential moodboards for communication and inspiration throughout the MDD process.

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Upcycling Reclaimed Wood, A Preliminary Analysis

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Abstract

One prominent strategy in achieving sustainability is upcycling, which is necessary for the transition of a post waste society. Craft has adopted the different ways of being in the world and can act as agent of change in the direction of sustainment. This study started with the aim to answer the question “Can I make something with this material, and if yes what can I make?” Poplar veneer and plywood strips were obtained by disassembling fruit crates and were used in the construction of flat and moulded plywood. Two types of adhesives were chosen for the manufacture of the specimens; Polyvinyl Acetate (PVA) and Liquid Hide Glue. During summer 2016, a total amount of 58 specimens was manufactured; the whole procedure was handcrafted. The specimens were subject to 3-point bending tests using a Universal Materials Tester. According to the test results, the Bending Strength of flat specimens was affected both by the number of layers (3 and 5 plies) and the type of adhesive used in each case (PVA and Liquid Hide Glue). The highest mean Bending Strength value proved to have derived from the 5-ply plywood laminated with Liquid Hide Glue. Referring to the Modulus of Elasticity value, Liquid Hide Glue appeared beneficial in increasing specimen’s Bending Stiffness and consequently Modulus of Elasticity as well. The geometry of moulded plywood specimens seemed to be beneficial to their mechanical behaviour, since both ‘Single-curved’ and ‘Double-curved’ specimens presented higher values of force at failure and bending stiffness, as compared to the flat 5-ply plywood (PVA) specimens.

Keywords

Material; Upcycling; Sustainability; Craft; Plywood; Wooden fruit crates; Poplar

Upcycling is a creative strategy that can bring about new and increased value to something that was considered waste. We argue that whole systems upcycling can provide an interesting direction in respect to the transition for sustainability as it addresses environmental, social and personal issues associated with modernity. In the first section of this paper we present the theoretical underpinnings of this study and provide the rationale for researching the intersection between sustainability and craft. In the second section a preliminary case study is presented. For the case study the following steps were undertaken. First the source of the material was identified and mapped. In the second part the process of disassembling the fruit crates and creating the specimens. In the next part the new upcycled material has been put in a series of mechanical stress tests in order to understand the possibilities of the new material and lead the design process. In the final part of the paper we wrap up by presenting the conclusions and reflecting on the overall process.

Upcycling and Sustainability

Sustainability is a term that has grown to encompass a variety of issues and aims to address them on a societal, environmental and personal level. This wide perspective has led to the term sustainability to be a widely-contested concept. One way of navigating these, ontologically, treacherous waters is by visualizing approaches to sustainability in a spectrum with eco-modernist approaches on one edge and ideas of sustainment on the other edge. One defining aspect in this context is the answer to the question "Does reducing unsustainability lead to the emergence of sustainability?" Eco modernist approaches aim to minimise the unsustainability of our systems of production and consumption. On the other side of the eco-modernity-sustainment spectrum we find the transformative and radical ideas that emerge from the idea that reducing unsustainability to zero does not solve the root causes of unsustainability (Ehrenfeld 2013) but a new society has to be created based around a new system of values compatible with sustainability. "Almost everything is being done in the name of sustainable development addresses and attempts to reduce unsustainability. But reducing unsustainability, although critical, does not and will not create sustainability." (Ehrenfeld 2008) Tony Fry refers to the shift from modernity as Sustainment, "a state in which the total inertia of human socio-technical existence, including cultures and economies, act to secure rather than damage the possibility of long term futures. The Sustainment may be equated in scale with the epochal shift of the 18th century Enlightenment movement which founded many of the concepts and institutions that persist into the 21st century" (Fry, 2004).

One prominent strategy in achieving sustainability is upcycling. Upcycling is the process of transforming by-products, waste materials, useless, or unwanted products into new materials or products of better quality or for better environmental value. Upcycling is the opposite of downcycling, which is the other half of the recycling process. Downcycling involves converting materials and products into new materials of lesser quality. Most recycling involves converting or extracting useful materials from a product and creating a different product or material. (McDonough & Braungart, 2002) Upcycling is necessary for the transition towards a post waste society. The authors propose the adoption of two closed loops with regard to materials, the biological metabolism and the technical metabolism. Materials in the first category are safely biodegradable and are discarded in the ground where they act as nutrients to other forms of life. Technical materials that are not biodegradable are stuck in an endless loop of recycling (McDonough & Braungart, 2002). We might be able to achieve the complete dichotomy between technical and biological metabolism proposed by the cradle to cradle framework but this strategy is future facing. As such it is impossible to apply on monstrous hybrids, materials made up of both technical and biological nutrients, or other materials that are now considered waste.

Upcycling provides a direction that can address the amounts of waste we have already created and give new life to them. Freitag, a Swiss bag company creates bags by upcycling used truck tarpaulins, discarded bicycle inner tubes and car seat belts in order to create a messenger bag (https://www.freitag.ch/en/about/production%20). The process addresses sustainability on all levels proposed by the Quadruple Bottom Line (Walker, 2012). Creating a new product that enables to reduce the environmental impact of human activities creates new practical meaning, the creation of new jobs due to the low scale, low intensity production model creates new social meaning and, finally the finished product is a blank canvas on which the user will create meaningful experiences.

Sustainability needs a deep shift in our material culture in order to truly achieve the transitions necessary. Craft has adopted the different ways of being in the world and can act as agent of change in the direction of sustainment. (Kiem, 2011) Realizing the intersections between craft and upcycling points towards an integrated design framework that creates artifacts that embody a wide array of characteristics that are conductive to sustainability. Craft has a deeper virtue, that of embodied involvement. The craft artifact is inseparable from the craftsperson, the materials and the process of its creation. The qualification of craft practice is neither predicated upon established hand working, machine based skills nor new methods which employ advanced technology but rather on the articulated relation between hand and mind in making which secures a direct human presence, as the loci of power and knowledge, in the made (Fry, 1994).

In this paper, we present a case study on upcycling systems design. Upcycling systems design spans across material collecting, upcycling design, local production and public dissemination, it provides proposals towards a sustainable system that will cast impact on our strategies of waste handling and energy saving. As we already discussed the motivation behind undertaking such a process goes beyond waste management and environmental stewardship. Craft artifacts not only embody the craftsperson' s tacit and experiential knowledge they can also take the role of propositional artifacts with regard to aesthetics as they adopt a different aesthetic typology.

In addition, such artifacts exist by engaging in 'rituals of care' which can strengthen and foster the values of reciprocity, thankfulness and conviviality towards both the human and the non-human. 'Beauty in use'. (Tonkinwise, 2003) In contrast with the two traditional ideas of beauty, the Platonic idea that the beautiful is a tool for contemplation of the truly eternal, that which exists outside time, and the Kantian thought that the beauty is based on the consensus of what is acknowledged as perfect, Tonkinwise proposes a shift from the metaphysical idea of beauty where "the beautiful needs no sustenance; it is anorexically self-satisfied. It puts us in touch with pure reason". This interaction with the designed requires a novel material culture as it can only be a paradox in the modernist project where planned obsolescence is part of the design process (Tsaknaki & Fernaeus, 2016).

All of the above point towards a holistic approach of designing craft artifacts through upcycling that can exist within the framework of transition design due to the threefold meaning embodied in the craft artifact. We propose the following steps for such a process

1. Identify sources of possible material to be upcycled.
2. Experiment and develop the material upcycling process.
3. Test what mechanical and aesthetic properties the upcycled materials offer.
4. Prototype craft artifacts in an iterative manner.
5. Scale up and go to production.

In this study, we will focus the second and third steps of this process. We feel as they provide the basis in terms of feasibility for any upcycled material. This study, for example, started with the aim to answer the question "Can I make something with this material, and if yes what can I make?"

Case Study

Phase 1: Identification of the material to upcycle

Initially, research took place on various products and materials that an average household in Greece consumes and throws away daily in order to decide which material will be our candidate for upcycling. Of particular interest were the non-recyclable items which are not allowed to be recycled in the traditional way. Such items for instance, are the disposable plastic bags, the cardboard boxes lined with plastic, the light bulbs, the metal clothes hangers, the Styrofoam containers and many others. However, many of the above have already been upcycled. This caused as to shift our focus on another material that is easy to recycle and yet it ends up in landfills in great numbers every year. This material is the wood used in packaging and other design ephemera. So, various wooden structures were examined, such as pallets and packaging boxes of any kind. Reusing wood prevents unnecessary landfill and reduces the need to chop down trees for new wood. Even though there have been serious attempts in cultivating hybrid forest trees to avoid burdening the environment, the demand on wood is still increasing significantly as well as the uncontrolled logging and deforestation. Consequently, there is an urgent need to reduce both the volume of wood waste and the environmental impact of logging.

Inspired by the trend for local and handcrafted production as well as for upcycling in order to maximize products' life cycle; we will study the process of transforming useless or unwanted products into new products or materials of greater value. Such a product is the wooden fruit crate which is used often only once and then thrown away. Through this process, it will be able to have a new purpose instead of being waste. Thereby reducing the volume of waste and the consumption of new raw materials.

The study took place in Syros, Greece, at the Department of Product and System Design Engineering, University of the Aegean, and so the wooden fruit crates needed for the experiment were collected from Syros's central market where a grocery store was throwing away approximately 70 wooden crates daily during summer. These wooden crates are usually produced by small-sized factories in Greece, and mainly used for fruit distribution all over the country. In the production, they are using trees cultivated in Greece and the type of wood mostly chosen for the manufacture of fruit crates is poplar.

Fig 1. Hybrid poplar trees in Greece.[1]

Poplar (genus *Populus)* is a tree that grows fast in height, 15-50 m tall, with trunks up to 2.5 m in diameter. Its bark is white to greenish or dark grey (Yadav et al., 2009). Poplar wood is used extensively for the manufacture of light packaging, such as cheese boxes, small crates for fruits and vegetables. It is commonly processed as plywood since it is valued in furniture and packaging. However, the veneer type that it produces is typically of poor quality with defects on its surfaces. In addition, the veneers extracted from the used fruit crates have their own defects too, for instance they may have been coloured by fruits. The defects that might affect the mechanical behaviour of those veneers are:

- The loads that crates sustain during their useful lifecycle (cracks and breaks on surfaces),
- The metal joints used in the assembly process of crates (rust and holes on surfaces), and
- The ambient conditions in which crates are exposed during their entire lifecycle (warping faults and colouring by the sun).

Thus, during the search for crates only those with minimum imperfections on wooden parts as well as those which appear to be in better shape were selected.

The objective of this study is the development of a new material through the upcycling process of the wooden fruit crates, in order to determine with experiments the possibility of re-using it in low-scale furniture production. Moving towards sustainability, our goal is to re-use all the wooden parts of the crate both the veneers and the painted plywood frames to avoid the loss of raw material and to keep as well the distinctive characteristics of the crate in the new product. Also, considering all aspects of the design and manufacturing process our aim is to create a closed-loop cycle in which only recyclable and non-toxic materials will be included, so as to develop a strong waste material for furniture design both socially and culturally acceptable. According to the above, plywood seemed to be the most appropriate choice to develop.

[1] http://www.ngorong.club/9473/hybrid-poplar-tree-growth-rate/

Phase 2: Experimentation on material's upcycling process (and specimens' fabricating process)

We decided to use the veneers from the reclaimed fruit crates to recreate the famous Lounge Chair by Eames; a significant reference to plywood furniture design. It is a chair that combines plywood with curved surfaces in a very attractive way. Actually, curved surfaces are difficult to create, especially negative double curved surfaces such as Lounge Chair's seat. Thereby, it was decided building and testing the mechanical behaviour of Lounge Chair's seat, in a smaller scale, but also examining how the developed material may eventually be affected by changes in its thickness, construction components and geometry. At the same time we felt that the choice of a design classic, beyond the technical issues to put forward the debate on intellectual property and creative commons.

The specimens' fabricating process consists of several phases. The first step is to find and collect the wooden crates which are destined to the trash. Then, follows the disassembly of the crates follows, as shown in Figure 2, and the storage of veneer and plywood strips according to their width and length.

Fig 2. Photographs of the disassembling procedure of a wooden fruit crate.

The following step is to decide the dimensions for the specimens that will be manufacturing and the dimensions for the veneer strips that will make up each layer of the plywood specimen. For this purpose, the strongest veneer strips are selected and cut lengthwise to the desired dimensions. Then, they also are cut crosswise to the appropriate proportions, while achieving their levelling as well. After that, the surfaces of the strips are rubbed and cleaned, for the best possible glue lamination. Finally, they are assembled, temporarily, with a masking tape in order to build the veneer sheets of the desired final dimensions, as shown in Figure 3.

Fig 3. Photographs of the cutting and assembling procedure of the veneer strips, in order to build the veneer sheets of the desired final dimensions.

The adhesives used in the construction of the plywood samples were Polyvinyl Acetate (PVA) and Liquid Hide Glue. The main criteria for the choice of these adhesives were, the cure temperature considerations of the adhesives, the behaviour of the bonding and the toxicity levels emitted at ambient conditions.

PVA is a non-toxic, aliphatic resin emulsion that is water based and is available in white and yellow. The white type is better for interior use because moisture weakens it over time, but it is very easy to apply and develops strong bolding strength on wood (Sideras, 2011) (approximately 25 MPa). It, also, offers a satisfying open assembly time (4-6 minutes), fast speed of set to reduce clamp time (10-15 minutes) and cures in room temperature (above 10^{o}C).

Liquid Hide Glue is a non-toxic natural adhesive that is manufactured from rendered collagen from the skins (hides) of animals. (Grigoriou, 2009) The difference between hide glue's original and liquid version is that the latter has urea added to keep the glue liquid at room temperature and to extend drying time[2]. Consequently, Liquid Hide Glue provides long assembly time (10 minutes), develops exceptional strength (approximately 25 MPa) and cures in room temperatures (above 10^{o}C). The total assembly time is 20-30 minutes.[3]

The following steps are determined by the final geometry of the samples.

For flat specimens' manufacture, adhesive is applied to one of the two surfaces to be laminated, using a brush or roller, so as to be spread equally over the entire surface. Once all the layers are glued together, having their wood grain rotated at 90 degrees to one another, pressure is applied until the glue dries. The pressure is achieved by clamping and stacking the specimens between two flat surfaces. The total assembly time depends on the glue.

In order to study the influence on the new material's mechanical behavior of the type of adhesive, the number of layers and the use of both of veneer and plywood parts collected from the crates, more than one type of flat specimens was built. As shown in Table 2, the following flat specimens were manufactured, having their grain crossed as follows, 0/90/0 in 3-plies and 0/90/0/90/0 in 5-plies, '0' being parallel to the width of the specimen.

3-PVA	10 specimens	3 veneer plies	PVA	150x180x5.5 mm
5-PVA	10 specimens	5 veneer plies	PVA	150x180x9 mm
5-Hide	8 specimens	5 veneer plies	Liquid Hide Glue	150x180x9 mm
Sandwich	10 specimens	2 veneer & 1 plywood plies	PVA	150x180x7 mm

Tab 2. Flat specimens.

As for the curved specimens' manufacture, two types of mould were built, one with single curvature and one with double. The specimens were placed one at a time on the moods while the applied glue was still wet on the veneer layers. The bending of the plywood sample was achieved in a vacuum press bag, as shown in Figure 4.

2 https://en.wikipedia.org/wiki/Wood_glue
3 http://www.titebond.com/product.aspx?id=9e9995b4-08eb-4fc6-8254-c47daa20f8ed

Fig 4. Photograph of molding in vacuum press bag.

As shown in Table 3, the following curved specimens were manufactured.

Single-curved	10 specimens	5 veneer plies	PVA	210x180x9 mm
Double-curved	10 specimens	5 veneer plies	PVA	210x180x9 mm

Tab 3. Curved specimens.

The samples were constructed with veneer strips of 1 mm and 1.5 mm nominal thickness. The total number of manufactured specimens was 58 and the whole manufacture was handcrafted.

Phase 3: Mechanical tests of the developed material

Fig 5. Bending test set up.

The 3-point bending tests, as shown in Figure 5, were carried out on a Universal Testing Machine (Shimadzu Tensile Tester) and the results for each specimen were presented in a Force (N) – Displacement (mm) diagrams. All the specimens were loaded perpendicular to the grain in the outer surfaces during the bending test. Figure 6 shows a photograph of one of the samples mounted in the materials tester.

Fig 6. Photograph of materials tester with one of the '5-Hide' specimens.

The rate of crosshead motion was adjusted at 0.03 mm/sec and 0.02 mm/sec for samples of 3-ply and 5-ply poplar plywood respectively, and the outer-fiber strain factor was equal to 10^{-3} per minute, so that the maximum load to be reached within 6 and 20 minutes throughout the test. (Brandt & Fridley 2003)

The bending strength, σ_f, and the flexural modulus, E_f, were calculated using the following equations,

$$\sigma_f = \frac{F_f L y_m}{4I} \qquad (1)$$

Where, F_f is the force at failure, L is the span, y_m is the maximum distance to the neutral axis and I is the moment of inertia, and

$$E_f = \frac{SL^3}{48I} \qquad (2)$$

Where, S is the bending stiffness.

Results and Discussion

The results of the strength properties of flat specimens tested are listed in Table 4 below. The bending strength was noticed higher at samples of '5-PVA' compared to those of '3-PVA', due to the increase of their thickness.

Specimens	Flexural Modulus E (MPa)	Bending Strength σ (MPa)	Bending Strength's St_Dev (MPa)
3-PVA	217.7	6.8	1.2
5-PVA	302.1	8.5	1.6
5-Hide	318.5	10.1	2.1
Sandwich	233.6	10.3	2.8

Tab 4. Strength properties of flat specimens tested.

As regards to the performance of the adhesives, the bending strength for specimens that were laminated with Liquid Hide Glue appeared higher than that for PVA, but observing the bending strength's standard deviation values in Table 4, for '5-PVA' and '5-Hide' specimens, it is uncertain whether the Liquid Hide Glue effected positively on the bending strength due to the small number of specimens tested.

Even though 'Sandwich' specimens presented the best behaviours in bending strength, the existing plywood layer in the specimen was delaminated from the other two layers at a very early stage of the bending test as shown in Figure 6, pointing that these samples did not perform as a single material.

Fig 6. Photograph during 'Sandwich' specimen bending test which shows the early delamination of the existing plywood layer from the other two veneer layers.

In fact, the bending strength in all specimens appeared low, about 1/3 lower than the expected, regardless of the number of layers and the type of adhesive (DLH Norge AS n.d.; Bal & Bektaş 2012). The strongest factor in determining the strength of plywood is continuity in each layer in the direction of the load. The plywood specimens are manufactured by assembling veneer strips and not uniform industrial veneer sheets; the resulting strength is expected to be lower. In addition, the wood grain in the outer surfaces of the samples (samples were loaded perpendicular rather than parallel to the grain) is not oriented for maximum strength. Lastly, taking into account the imperfections of the raw material it is not very surprising that this construction deviates considerably from the literature values of poplar plywood.

The bending stiffness, S, for ‘5-PVA’ should be estimated approximately 4.4 times higher than that for ‘3-PVA’ since it is related to specimen’s thickness (Eq. 2), if the elastic modulus was a material constant independent of the number of layers. However, the elastic modulus for ‘5-PVA’ specimens is calculated approximately 6.1 times higher than that for ‘3-PVA’. This increase probably occurs due to the addition of a veneer layer in ‘5-PVA’ samples loaded parallel to wood grain which is closer to the external surfaces of the sample, where the stresses are higher as shown by the sketch in Figure 7.

Among the samples laminated with a different type of adhesive, the elastic modulus was influenced only by samples’ stiffness, since their thickness was the same. Thus, Liquid Hide Glue appeared beneficial in increasing specimen’s bending stiffness.

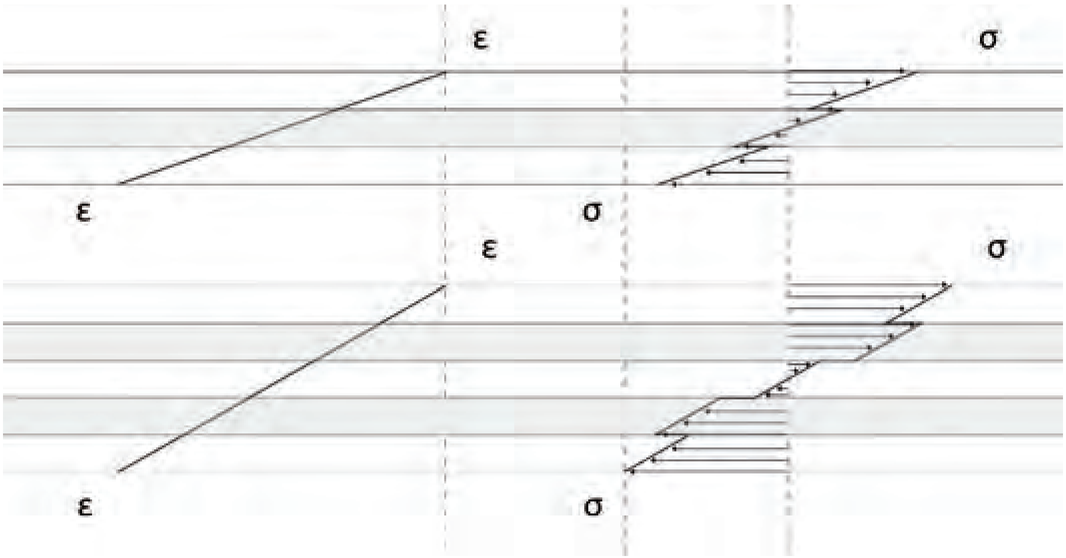

Fig 7. Schematic draft of stress distribution for ‘3-PVA’ and ‘5-PVA’ specimens. The same deformation (ε) leads to higher stresses (σ) for veneer layers loaded parallel to wood grain (layers in grey color).

The results of the curved 5-plies plywood specimens tested, which were laminated with PVA, are indicated in Table 5 below, compared to ‘5-PVA’ specimens’ values of force at failure and bending stiffness.

Specimens	Force at failure F_f (N)	Bending Stiffness S (N/mm)
5-PVA	879	131.9
Single-curved	2434.6	203
Double-curved	2310.3	137.7

Tab 5. Strength properties of curved specimens tested.

The geometry of curved specimens seemed to augment their mechanical behaviour, since both ‘Single-curved’ and ‘Double-curved’ specimens presented higher values of force at failure and bending stiffness, than those observed for ‘5-PVA’ specimens. In particular, the best mechanical behaviour was presented by ‘Single-curved’ samples in which the crack growth at the lower layers developed by tensile stresses was suspended by their geometry and so the failure in the material appeared at higher loads. The curvature of the cross-section works as a restriction on the deformation as well. A similar behaviour was recorded for ‘Double-curved’ specimens. Although local failure was observed, caused by cracks or delaminations in relatively low loads, it did not seem to influence neither the material’s structure nor the increase in force.

The bending stiffness for ‘Single-curved’ specimens was increased by 53.9% relatively to that for ‘5-PVA’ due to the change in samples’ geometry. On the other hand, the ‘Double-curved’ specimens did not present similar behaviour regarding their bending stiffness. This seemingly inconsistent behavior may be a result of both the approximate calculations made for stiffness on the force-displacement graphs recorded by the bending tester and the fact that at the beginning of the test the crosshead was not in absolute contact with the sample.

Conclusion

The mechanical properties and behaviour of poplar plywood manufactured using the wooden parts of a fruit crate were investigated and the following results were obtained.

- The bending strength of flat specimens was affected both by the number of layers (3 and 5 plies) and the type of adhesive used in each case (PVA and Liquid Hide Glue).
    - The bending strength for ‘5-PVA’ is 25% higher than that for ‘3-PVA’ specimens.
    - The bending strength for ‘5-Hide’ is 19% higher than that for ‘5-PVA’ specimens.
    - As for ‘Sandwich’ specimens, it seems uncertain whether the existing plywood layer was helpful to the material’s mechanical behaviour due to both the early failures that occurred in the material and the bending strength’s standard deviation values.
- The elastic modulus, even though it is considered as a property of the material, appeared different in ‘3-PVA’ and ‘5-PVA’ specimens, indicating that with the addition of two extra layers the material is no longer the same and its mechanical properties are substantially different.
- The geometry of curved specimens seemed to be beneficial to their mechanical behaviour, since both ‘Single-curved’ and ‘Double-curved’ specimens presented higher values of force at failure and of their bending stiffness, as compared to ‘5-PVA’ specimens.
    - The failure load for ‘Single-curved’ and ‘Double-curved’ specimens is almost three times that for ‘5-PVA’ specimens.
    - The bending stiffness for ‘Single-curved’ specimens is 53.9% higher than that for ‘5-PVA’ specimens.
    - As if it is not possible to compare the bending strength of ‘5-PVA’ specimens to that of the curved ones, due to their difference in cross-section, it appears that the latter, because of their geometry, presented higher values on toughness since it was too difficult for the cracks that appeared to grow and cause significant changes in the structure of the material.

Reflection

Upcycling is a process that enables the reuse of waste as raw material and thus leads to the reduction of the exploitation of natural and energy resources as well as restrict CO_2 emissions. The most important conclusion, which can be drawn through this study, is that waste materials and useless or unwanted products are able to become useful once again, to obtain a new identity and ecological value and challenge contemporary material culture. At the same time, it is worth mentioning that upcycling is a process through which people flourish by increasing their creativity, ingenuity and confidence in their capacity to craft. Finally through the process the notion of waste is challenge nudging people towards a post waste society.

As for the new material, it presented promising mechanical behaviour especially if we take into account the raw materials origin and defects. Both the increase of specimens’ thickness and curvature yielded satisfying values of mechanical and strength properties. At the same time the high values of bending strength due to the use of Liquid Hide Glue, an adhesive that is compatible with the values of sustainability due to its natural non-toxic origin, are remarkable. Engaging in a process of material driven design (Karana et al. 2015) with the final plywood material to create the kind of furniture that embodies the Eames's character are certainly the next aim of this project.

Additional research and tests are necessary in order to verify the mechanical and aesthetic properties that the upcycled material has to offer. So, future work will be the repetition of bending tests while making some changes in the manufacturing process as well as on parameters that affect the mechanical properties of the material. Such parameters to be considered are, the basic measurements of veneers' density, moisture content and thickness and also the direction of wood fibres per layer in accordance to the normal stresses.

Once the mechanical properties of the new material are fully examined, the next step undertaken will be the experimentation of prototyping a piece of furniture. The next steps once this is successful will be to scale up and design an appropriate production model that fulfils the requirements of the carpentry community, consumers' growing interest around upcycling and the necessary transitions towards sustainability.

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Exploring unique material characteristics by combining textile waste with biobased plastics

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Keywords
Biobased plastics,
Textiles,
Innovative material-combinations
Circular products
Mechanical & aesthetic characteristics

Abstract
New material combinations can offer new opportunities by providing unique material characteristics (e.g. strength, stiffness, look & feel). This pictorial shows the first results of research with regard to combining textile waste and biobased plastics. New materials are created and tested and application possibilities are explored. Aim of the research is to explore and demonstrate lasting and recyclable products from these new materials for the companies who provided textile waste. Next to the unique material characteristics, the developed materials and products should also have economic and ecological value, as well as contribute to the transition towards a circular economy.

Introduction
While the amount of waste continues to grow, raw materials become scarcer and more expensive. The circular economy offers solutions to these growing problems. Within the developing circular economy, bio-based materials are on the rise and close attention is paid to reuse and recycling. New business models are being developed around waste reuse and value creation (EMF, 2013).

Lots of research has been done on biocomposites, biobased plastics and processing textile waste streams, but not on combining these. As most research focusses on mechanical properties and costs, while aesthetic, tactile and emotional aspects, crucial for commercial value, are only very limited researched.

Biocomposites
For the production of biocomposite products so-called virgin natural fibers are combined with biobased plastics. Research done in the past shows that market opportunities for biocomposites are good, in spite of many optimisations which are still possible and useful (Faruka ea, 2012). Important issues that support these market opportunities are lower environmental impact, low specific weight and aesthetic properties (Böttger, Lepelaar, & Bouvy, 2009; van Beurden & Goselink, 2013; van Rooijen, 2012). Not many appealing examples of inspiring and successful products are available. Most examples are not yet in large scale production and knowledge concerning experiential qualities are limited and not widely explored.

Biobased plastics
Many biobased plastic blends and grades are commercially available (Iles & Martin, 2013; Bolck, Ravenstijn, Molenveld, & Harmsen, 2012). Some of these are biodegradable. Often, these biobased plastics are not 100% sustainable due to blending with non-natural additives (for improving properties or process ability) or fibers (Alvarez-Chavez, Edwards, Moure-Easo, & Geiser, 2012; Bolck et al., 2012). Knowledge of processing biobased plastic is limited to only a few plastic processors who have gained experience.

Textile waste streams
In the Netherlands several knowledge institutes, organisations and companies are involved in collecting and recycling textile waste. Value is created in the so-called clothing-clothing recycling (selling second hand clothes), resource recollection and recycling to products with a relatively low added value (like cleaning cloth or isolation materials (Bottenberg, Goselink, & Bouwhuis, 2013)).

Circular Biocomposite of biobased plastics and textile waste streams, RECURF
The aim of the research is to explore and develop new materials suitable for the design and production of circular products with economic and ecological value. This is done through cooperation between different disciplines such as functional material research, product design, engineering and business modelling, also combining research and practice.

In the first stage of the research several tests are performed to find the most favourable material combinations, with regard to production technology, mechanical characteristics and aesthetics, tactiles and emotional qualities (experiential qualities (Karana, 2015)). Theoretically, a vast range of combinations is possible, given the different sorts of received textiles and available biobased plastics, as well as the choice of fibre length and processing methods.

In this pictorial we focus on the assessment of processing techniques, mechanical properties and experiential qualities and the exploration of applications through some first product ideas and prototypes.

The research focuses on the following areas:
- the mechanical and experiential qualities of the material combinations;
- the appropriate processing techniques and design strategies for application of these materials;
- the circular nature of the designs, including environmental impact and end-of-life scenarios;
- circular business models with an interesting value proposition and revenue model.

The research combines two sectors and two materials (biobased plastics and textiles) to create new, unique material combinations with favourable mechanical and aesthetic characteristics. The mechanical strength of the new materials is often better than that of alternative materials. Also they are light and have favourable aesthetical characteristics (Böttger et al., 2009; van Beurden et al., 2013; van Rooijen, 2012). As shown by Karana (2012) and Van der Wal (2015) the aesthetical and tactile characteristics are an added value to the perception and appreciation of the natural origin and quality of biobased products.

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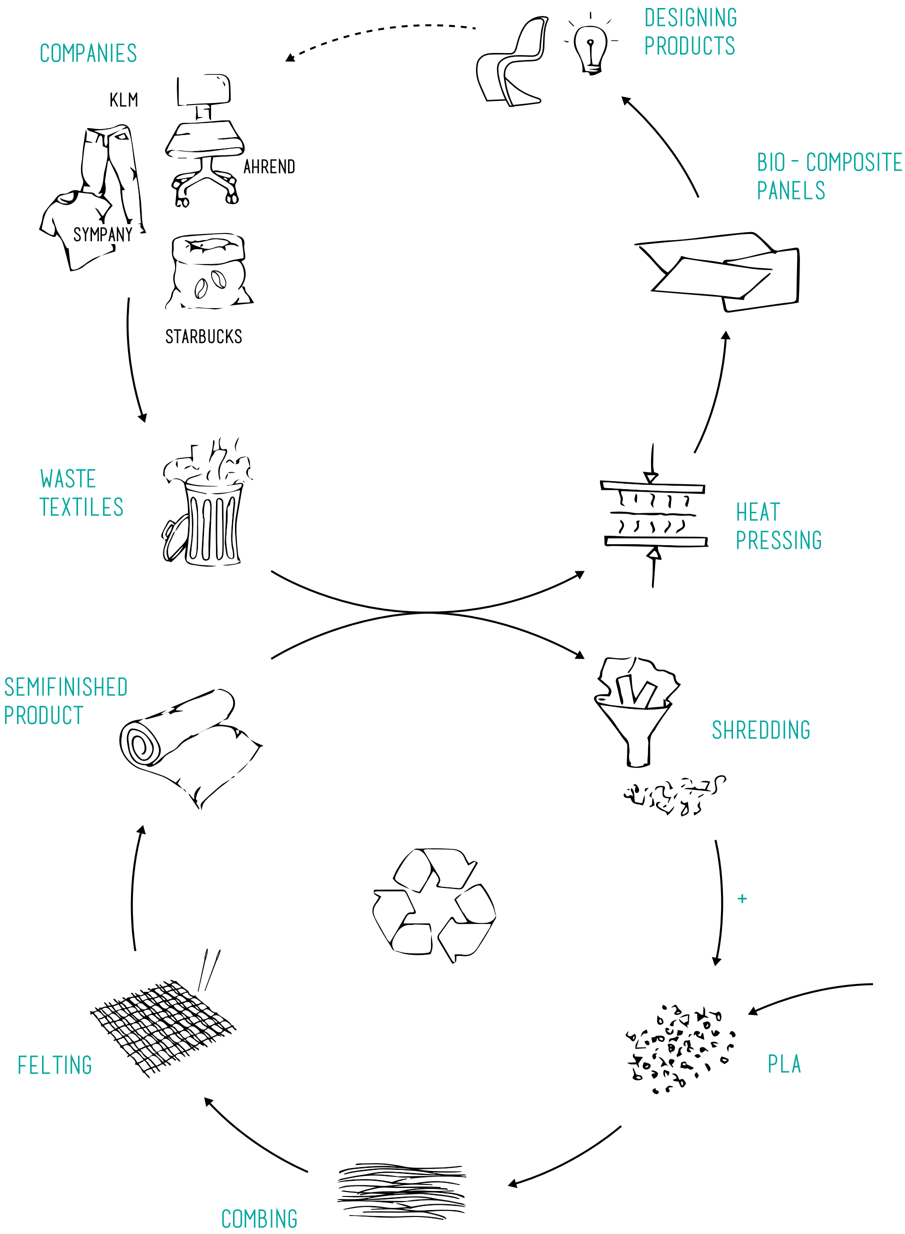
The figure on the right gives an overview of the circular development process of the new materials and products.

Also the Amsterdam metropolitan area is committed to the circular economy, reuse and recycling and strives to a circular city and waste chain (Gemeente Amsterdam, 2014).

The residents of Amsterdam produce an average of 17kg of textile waste per person per year. Only 16% of this waste is collected separately (Gemeente Amsterdam, 2015). The rest ends up as residual waste and will be incinerated. Only a part of the separately gathered textile is suitable for reuse or high quality recycling. Research question is whether it is possible to combine (non-reusable) textile waste fibres with bio-based plastics to create new materials with unique properties.

Companies such as Starbucks, Ahrend and clothing collection organisation Sympany, are providing some of their discarded textiles to investigate whether the combination of this extra recycling route can help to produce innovative circular products for their own use.



Preprocessing textiel fibres

The raw textile material is processed in three different ways: woven, fiberised and pulverised. The material samples have varying fibre lengths, suitable for the different types of production techniques, such as hot pressing, vacuum infusion, 3D-printing and injection moulding. For demonstration purposes jute is chosen as an example. Other fabrics used are denim (cotton), uniforms (cotton/polyester) and furniture upholstery (wool).

Textile wastestream: jute coffee bags, in which the raw coffeebeans are transported from a worldwide scatter of suppliers to the Starbucks coffee processing factory in the Amsterdam harbour. Approx. 240 tons/yr.

Woven jute

Fiberised jute

Pulverised jute

Woven jute with Solanyl (TPS-based bioplastic) hot pressed

Fiberised and needle punched jute and PLA hot pressed

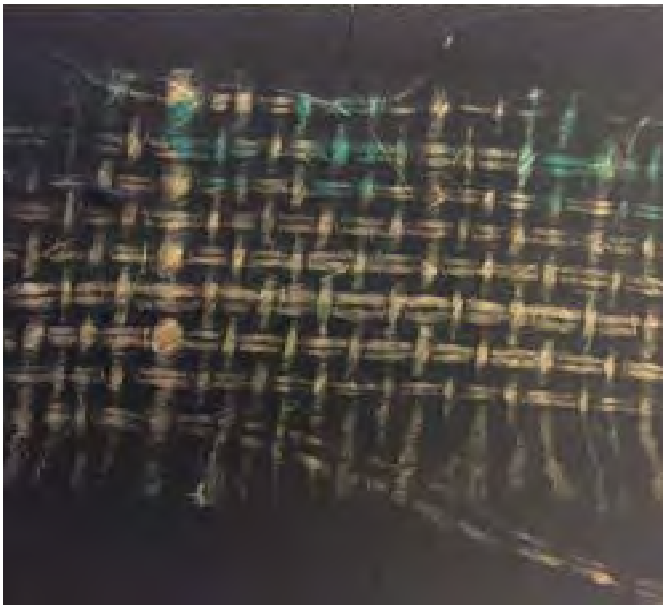
Pulverised jute with PLA tension bar plus granulate

Woven textiles combined with biobased plastics - material samples

If the textile is directly, without hardly any preprocessing, used in circular biocomposites the full strength of the original textiel adds to the mechanical properties in the material combination. Also is the visual feedback most direct; in this case the jute bag or in other cases the jeans pants are still recognisable. So it is clear to users what the origin of the used textile waste stream is. It has a very strong recylce or “eco” appearance. However, upscaling production is hard to realise in an industrial and continuous manner because of handling and maxmum size of the textile cloth.

Jute mat with PLA granulate

Jute mat with Solanyl sheet



Recycled PLA

Fiberised textiles combined with biobased plastics - material samples

In most cases the first step in recycling non rewearable textiel waste is fiberising the collected cloths. This leads to randomly ordened fibres with a typical length of about 30mm's. If we combine these fibres with biobased plastics a more amorphous look is created, allthough it is still very clear that the material consists of a fibre like material. The tactiles have a soft touch smooth surface, but not as smooth as pure plastic. The fiberised fibres can be processed by needle punching into continues rolls of non wovens with a defined weight per m2 and are therefore very suitable for industrial processing.

Jute with Solanyl (PLA/TPS)

Denim with PLA fibres

Uniform with Solanyl (PLA/TPS)

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Fiberised textiles combined with biobased plastics - examples of (digital) processing

When needlepunching the fiberised textiles in non wovens a biobased plastic PLA fibre can be integrated. This non woven can be heated and pressed into sheets or directly in sheet based shapes/products. The sheet based products can be post processed by digital production techniques like lasercutting. It is also possible to create sheets and products that can be rigid as well as soft.

Denim and PLA
Laser cutting before pressing

Jute and PLA
Laser cutting combining hard and soft

Uniform and PLA
Local hot pressing hard and soft

Denim and PLA
Laser engraving

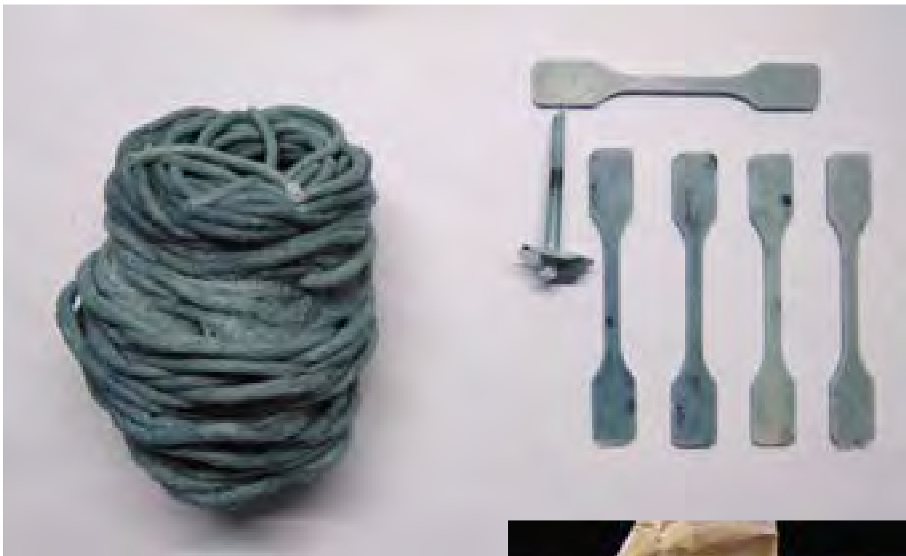
Uniform and PLA
Laser cutting

Pulverised textiles with biobased plastics - material samples & processing techniques

When processing plastic in most industries the plastic is process as a granulate of approximately 3x3x3 mm. In order to be able to proces a fibre fileld plastic biocomposite the fibre length should be no longer than 3 mm. To achieve this the fibres are pulverised and compounded into granulate. After doing so the granulate can be processed through fe. injection moulding or 3D printing.

Granulate from Solanyl (PLA/TPS) and denim

Cotton dust from filter and Cradonyl (PLA/TPS) hot pressed



Denim and PLA/TPS
Injection moulded

Jute and PLA
Filament 3D-printing

Delft University of Technology, The Netherlands

Exploration of applications - woven textiles combined with biobased plastics

Besides making square and flat samples it is usefull to explore and demonsrate the new material combinations in products as well. The ultimate goal of using material is using material in useable products.

Serving trays made from a.o. jute mats and Solanyl (PLA/TPS) Hot pressing

Tabel Minor New Materials

Material: Jute bag, jute fiberised and PLA non woven
Processing method: Hot pressing, laser cutting.

Exploration of applications - fiberised textiles combined with biobased plastics

Since the fiberised fibres are usable in industrial production techniques most prodcuts that are further elaborated are using these fibre/plastic combinations. Properties of the materials, like aesthetics, mechanical, emotion, biodegradability etc. are used in strengthening the designs.

Surf board Fin

Material: denim/ jute PLA in non woven
Processing methode: Hot pressed into sheet, laser cut, hot pressed

Lounge chair

Material:
Combination of Jute and UP
Processing methode:
Bulk Moulding Compound,
Hot press

Spectacle case

Material:
Combination of Denim and PLA
Processing methode:
Hot press

Results and discussion

Creating new matierals by combining textile waste and biobased plastics offers a great range of different appearances, forms and formats. Applying several processing methods expands this range even more. The new material combinations have varying mechanical characteristics and perceptive forms: from smooth to rough, from glossy to mat/dull, from flexible to rigid. The new material combinations have a new and unique look and feel and perceptive values.

Also the physical and mechanical characteristics are interesting. Mechanical properties in comparison to pure biobased plastic could be increased up to 50% in strength and 66% in stiffness (when combining PLA granulate with 30% pulverised jute)(Callenbach, 2016). At the bottom scale of mechanical properties it was possible to at least keep mechanical properties constant, while saving on costs for biobased plastic. Textiles combined with biobased plastics can be processed into materials with interesting physical properties like sound-damping and vibration-damping qualities, products can be engineered very lightweight or very strong and stiff and they can combine hard and soft in one material.

The search for material combinations and suitable matching product applications has just begun. Together with partners from research and industry, such as the TU Delft and several medium sized companies (SME's) from the biobased plastic chain, the most promising material combinations, processing methods and applications have been identified and will be further developed. Material samples and prototypes are produced to better understand the relationship between material, process and form. Most pictures show the original colours of the textiles and plastics. Experiments with pigments and mould surfaces have not yet been done, and offer additional possibilities with regard to the experiential qualities.

Material samples and prototypes are produced to better understand the relationship between material, process and form. From this understanding the research partners have concluded that further research on sheet based products for interior use is most promising. Further research on the whole value chain is recommendable in order to optimize circularity and commercial feasibility. The promising result on the exploration of using flexible digital production techniques to customize products, shapes and appearances should be elaborated and further explored.

Acknowledgment

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Tangible opportunities: Designing material studies and toolkits for school-aged children

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Abstract

Touching is one of the best ways humans to communicate with the world around them. For many decades, a tactile learning approach has been applied in child education as one of the most effective learning methods to maximise children's learning ability. However, there are few approaches and toolkits that enhance tactile material study on education for school-aged children. This study introduces and demonstrates different approaches of material study with different age groups of young people. It presents the benefits, implementation and challenges of the material study in children's education. The aims are three-fold: 1) to stimulate children's interest in and recognition of materials, 2) to demonstrate material study approaches with different aged children, and 3) to accentuate the benefits and limits of the material study approaches. As the results significantly reveal, materials as a medium offer children valuable opportunities to lively develop ideas, actively participate in developing curricular, and adaptively learn new knowledge and skills through practice. These findings suggest that materials engage children's motivation, participation and satisfaction in their own learning. Furthermore, this research provides adults with a feasible understanding of and communication with children in the design process.

Keywords

Materials; Material study; Learning by doing; Education for children; Toolkits

Children learn new things as well as express their thoughts and emotions through distinctive senses, such as sight, hearing, touch, smell and tastes. This begins during the infant stages of child development: babies learn from and adapt to the new world through touching objects with their hands and mouth. This learning and experiences through the senses has been applied to children's development and education. For instance, the Montessori approach, a well-know philosophy in child education instigated by Maria Montessori in 1906, encourages harnessing the materials available in the surrounding environment to promote learning through hands-on-activities. Thus, as a designer, the author's focus is on promoting this aspect of learning through material study.

Another aspect to consider is the optimal avenue through to analyse children's experience of this type of learning. One tool for this has been the analysis of their drawings to interpret their perspective and experiences (Piaget, 1970). In fact, drawings have recently been used to capture children's views to develop computer programmes (Sheenhan, 2003). They have also been employed in the field of pedagogy research to gather data about students' experiences (MacPhail & Kinchin, 2004), and in the child-centred approach as an advantageous evaluation tool (Xu, Read, Sim & McBanus, 2009). However, not all children are confident in drawing. To investigate children's general interests, the author conducted observational studies during children's activities in indoor and outdoor settings. According to her preliminary research, many of the children expressed difficulties with drawing and exhibited low confidence in this activity. Instead, they were more confortable and confident in dealing with tangible materials to develop their ideas.

Based on these early findings, this study focuses on children's material-experience and learning through hands-on activities. Based on the Montessori theory (Montessori 2004), a number of educational approaches have been developed to emphasise young children's tactile learning, namely, learning through these types of tactile activities. However, there are few studies and toolkits focusing on exploring materials for school-aged children. To fulfil gap, this study contributes to the fostering of tactile learning and material-experience for children (ages 7-18 yrs). Applied through a participatory approach involving the author, a design expert, they have been developed by working with children in Finland and South Korea, from 2012 to 2014.

The objectives of this study are three-fold: 1) to stimulate children's interests and recognition of materials; 2) to demonstrate different material study approaches according to different ages of children; and 3) to accentuate the benefits and limits of the material study approaches for further development. This study proposes that material study toolkits enhance children's education, including material recognition, tactile experience and idea development. These approaches could provide practical guidance to educators and other researchers involved in education and design for children and youth.

In the following sections, the author scrutinises other scholars' perspectives on materials in craft and design and defines the meanings of material in this study. As the preliminary research, she explores observational studies on materials in children's activities, and presents various material study approaches and toolkits have been demonstrated in three respective locations. All the toolkits are later analysed and evaluated. The discussion includes the accentuation of designerly ways and skills as well as the meaning of materials as a medium to offer young people diverse opportunities in their education. Finally, this study focuses on the validity of demonstrating and implementing material study approaches and toolkits in the primary school curriculum rather than comparing them against the other.

Meaning of material

Material encompasses distinctive meanings and perspectives depending on different contexts and situations. As a noun, it literally refers inclusively to a physical substance, information, cloth and equipment. Moreover, it can be not only an unprocessed raw substance, but also a source for a new cycle of production to create new substances and products. In this research, the term 'materials' refers to both physical substances surrounding us, and the artefacts developed for understanding and learning about the physical substance.

Based on Dewey's emphasis on a material engagement in process of thinking and reflecting in the field of art (1980), craft has stressed logical thinking and material engagement through the senses and process of learning and understanding through practices (Adamson, 2007; Mäkelä 2007; Nimkulrat, 2012). In particular, craft has emphasised intellectual thinking through the process of making materials into objects (Sennett, 2008) and the process of learning and understanding through material experience (Gray & Burnett, 2009). Carter addressed interaction between materials with the maker's hands, mind and eyes in a creative process (2004).

Whilst expanding the meaning of material in design, designers have attempted to explore new materials and improve the finishing qualities of products applying to the particular materials. However, beyond exploring new materials and improving the final qualities of products, the meaning of material has expanded its boundaries to other domains, such as data, information, toolkits, techniques and others depending on different contexts and situations. Many scholars have discussed about different aspects of materials in design research: for example, Ehn and Kyng's Cardboard computers (1999) and Eriksen's Material Matters in Co-design (2012). However, these references have not covered examples of working with variously aged children. To focus on children, Cooperative Inquiry (Druin 1999) has been one of the best known methods involving children in the design process in Child-Computer Interaction domain; therefore, several techniques have been implemented working with children in the design process. In particular, *Bags of stuff* has been comprised of arts and crafts supplements for low-tech prototyping, which has been one of the key frameworks in Cooperative Inquiry.

By emphasizing the learning process and understanding of material in craft, the Finnish comprehensive curriculum has equipped students with a diverse knowledge of techniques and materials, as well as management of tools (Seitamaa-Hakkarainen & Matinlauri 2015). Even though the Finnish education emphasises knowledge of materials, there are limited opportunities to learn about them in the school curriculum. Recently, this curriculum has been rapidly changing in many countries. One example of this change is the inclusion of real-life problem-solving exercises (Eggleston 1976). This type of exercise is also prevalent in design research and practice. Hence, design could tackle real context practices in children's education.

From 'FabLab@School' in Stanford University to "FabLab@School.dk' in Aarhus University, the maker principle has stretched to primary and lower secondary schools and strengthening the concept of the Scandinavian tradition of design and innovation processes. Beginning from these common foci on learning in crafts and design, Giannakos and his colleagues have discussed engagement and creativity in learning through making (Giannakos, Divitini, Iversen and Koulouris 2015). Inspired by the concept of FabLabs in education, this research strengthens its position by building on the fundamental experience of materials as substances, and learning through materials, which have been developed for and with children, as well as integrated into their comprehensive education.

Research method and framework

Inspired by Vygotsky's sociocultural Theory of Development (Vygotsky 1978) and Montessori's hands-on learning, this research has been framed by Cross' 'Designerly way of knowing' theory (Cross 1982; 2001). First, Vygotsky's theory states that children learn through social interactions and their culture; therefore, children's education should focus on activities that involve interaction with others. In line with Vygotsky's sociocultural development and learning, Montessori emphasises self-motivated learning through hands-on-activities with materials. The provided activities and materials create a learning environment, and this environment allows children to proceed at their own pace, to pursue their own interests, to develop concentration, and work based on their own wishes and desires. In this learning process, children develop emotionally, socially, intellectually and physically, and the teacher's intervention should be minimised and thoroughly defined. In the Montessori focus on tactile materials, 'materials' are called 'didactic tools' in their curriculum and served merely as tools for its implementation (Montessori 2004).

Cross has addressed on designing activities, involving designers, their creation process and artefacts (1982; 2001). He has revealed the requisite relationship between thinking and knowing in craft and designerly practices. There are five different aspects of the 'Designerly ways of knowing':

- Designers tackle 'ill-defined' problems
- Their mode of problem-solving is 'solution-focused'
- Their mode of thinking is 'constructive'
- They use 'codes' that translate abstract requirement into concrete objects
- They use these codes to both 'read' and 'write' in 'object languages'.

Based on this Cross' theoretical influence on this research, the preliminary research was conducted to investigate interaction and exploration between children and materials (substances). Afterwards, tactile materials (study approaches and toolkits) were initially developed during the first case study with different age groups of children. The materials have been utilised with one age group of children (fifth graders) to enhance their tactile learning and experiences in two different primary schools. This research provides children with tangible opportunities to learn designerly ways as well as the skills of solving problems and generating ideas, which were integrated into the children's education. The principles of the 'Designerly ways of knowing' with children will be elaborated on and refined in the Discussion section.

Research materials

To understand children's general interests, the author conducted observational studies on children's activities of indoor and outdoor settings in Helsinki, Finland in 2012. The activities were type of designerly and architectural activities. From the fundamental studies, the children revealed their thoughts, perspectives and interests through the outcomes and discussion during the activities.

The main findings from the preliminary research reveal that children interacted with materials in diverse ways. The interactions between the children and materials were illustrated at three different levels. First, the children enjoyed experiencing the material itself and expressing their thoughts and ideas through materials. Second, materials engaged related adults (i.e. the design researcher, designer and educators) to understand the children through materials during the activities. Finally, the children had opportunities to learn about designerly ways and skills through practice with the materials. The children showed extreme interest in and enthusiasm for distinctive materials. Hence, the author built up a hypothesis that material could encourage children to embody and develop their ideas. Based on this investigation, she planned an experimental approach of developing toolkits to enhance materials experience (Karana, Pedgley and Rognoli 2014; Karana, et al. 2015) for and with children.

The methods of material study have been planned and revised according to the children's ages and their previous material experience. All the material study approaches and toolkits: *material frottages, collages, image cards, palettes, matrices*, *sample kits* and *building blocks* were implemented according to children's understanding and experience of materials. Through these experiences, children could explore new ideas and experiences with various materials. Furthermore, children in this study, different material study approaches were introduced and demonstrated. Each approach had significant characteristics because they were designed for different circumstances and targeted at different aged children (Figs 1 & 2).

Cases

Based on the Montessori tactile learning approach, the author conducted experimental projects for children and youth to examine the material study approaches. The presented material study toolkits were demonstrated with different age groups of children, who had distinctive material and cultural experiences. The projects were conducted in two different locations in Helsinki, Finland as well as in Seoul, South Korea during September 2012 to November 2014. Each project included two main sessions: a material exploration session: understanding and experiencing materials (physical substances); and a design implementation session: designerly and architectural activities integrated in primary education. This research mainly focused on the material study approaches and toolkits rather than describing the diversity and implication of activities during the sessions.

Material frottages

Frottage is the technique of rubbing from an uneven surface to form the basis of a work of art. It could be an appropriate practice of touching or experiencing of different materials and surrounding, especially for young children, who have immature writing skills to explain and describe ideas. The children are provided papers and pencils to rub. Children initial look around and touch their surroundings. Afterward they rub from the surface of the surroundings or objects. The frottage shows visual depictions of materials and it can be a piece of artwork itself.

Material collages

Collage is a piece of art made by adhering various materials, such as photographs, pieces of paper or fabric on to a mounting board. It is one of the simple art activities without specific instruction. The aim of this technic is for children's material experience through touching, cutting and gluing different materials during making the collages. The children also write down the names of materials as well as describe different feelings and uses of materials on the backside of the collages. It improves children's language skills as well.

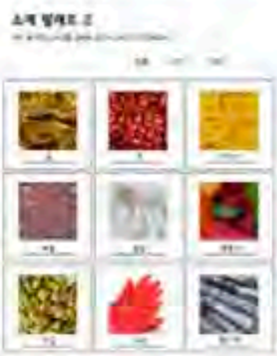
Material image cards

Each material image cards presents an image of material or object, which can be found in our daily life, on one side. There were two different material image card sets, which include six different material types, such as fabric, food, material from nature, metal, paper and plastic. The children can write down the material names, tactile feelings and different uses of materials on the backsides of the image cards. It improves children's language skills in a similar fashion as the material collage.

Material palette boxes

Material palette 1 is a cardboard paper box, in which can be stored different tangible materials. The idea has been initiated from a palette on which an artist lays and mixes colours. Children initially select materials from their surroundings without any other specific instruction or guidance. Children also collect some favourable materials from material sample kits within this palette for other activities.

Fig1. A description of different material study toolkits 1



Material palette sheets

Material palette 2 is a sheet of paper, in which can be collected and described children's favourite materials at the same time. Children describe names, tactile feelings and uses of the materials on the palette sheet. It shows children's fundamental understanding and previous knowledge of materials.

Material matrices

Matrices in mathematics are rectangular array of quantities or expressions in rows and columns that are treated as a single entity and manipulated according to particular rules. In rows and columns, there are opposite adjectives, which describe tactile sensitivities of materials, such as hard, soft, natural or artificial. Children compare different feelings of materials based on the given adjectives. This activity encourages children to create other tactile feelings on the matrices and initiate practice with them. It improves children's language skills and comparison practice.

Material sample kits

Around fifty different objects are represented different materials in the material sample kits. The objects are found and collected from dairy surroundings of participants; therefore, these are accustomed to them. Directly children touch materials and enhance their material experiences.

Material building blocks

Building blocks are designed for constructing three-dimensional models. These are two different sizes and made from two millimetre thick cardboard sheets. These are structured the dimensions of forty-five millimetres by forty-five millimetres with four grooves and ninety millimetres by forty-five millimetres with six grooves. Each side of the blocks has different material images or colours. The images on the blocks are adopted from the material image cards.

Fig 2. A description of different material study toolkits 2

Four different groups of children were recruited with which to conduct the case studies. The main target age group of children was seven to twelve years-old, mainly primary school children; however, the study was extended to children up to nineteen years-old for potential development of the study toolkits for adolescents. To develop initiative materials and increase its adaptability to a wide range of children, the first case was conducted in a special educational institute, ARKKI (Lasten ja nuorten arkkitehtuurikoulu), an architectural school for children and youth in Helsinki, Finland, with different aged children. Furthermore, two more cases were conducted in primary schools with one age group of pupils (fifth graders). A total of seventy-seven children (case 1. n=26, case 2. n=25, and case 3. n=26) participated in the projects. The author organised and facilitated all the projects as a design expert, and the classroom teacher assisted in the projects. During the projects, all the process and outcomes were recorded as photographs and videos. Additionally, the author wrote down any significant conversations held with children during the sessions, and feedback from the teachers afterwards.

Case 1. ARKKI

The first case was conducted in ARKKI, one after-school facility in Helsinki, Finland from September to December 2012. Each session lasted one and a half hours per week and the whole project five to seven weeks. The participants (n=26: 14 boys and12 girls) were of various nationalities, such as Finns, Russians, Americans, Poles and Italians; therefore, English was the official language, but Finnish was also used on some occasions. The pupils were separated into three different groups according to their ages (1^{st} group: 7-9yrs, 2^{nd} group: 10-12yrs, and 3^{rd} group: 13-19yrs). The author planned and facilitated the sessions as a design expert, and collaborated with the main activity teacher.

During the material exploration session, the pupils explored different material study approaches, such as *material frottages*, *collages* and *matrices*. Each group had different design inquiries in the implementation sessions after the material exploration. The participants in ARKKI were provided various materials during their ordinary activities; therefore, many of the children already had extended material experience. However, they were not given much time to explore the materials before initiating the designerly or architectural projects.

Case 2. Töölö Primary School

The second case was conducted in Töölö Primary School in Helsinki, Finland in January 2013. The sessions were conducted for two hours in a normal classroom setting with a classroom teacher. The participants (n= 25, 14 boys and 11 girls) were divided into six different groups (2 boy groups, 2 girl groups and 2 mixed gender groups). The pupils were in a bilingual class, and were fairly fluent both in Finnish and English. As such, the workshops were organised in English. In addition, a designer planned and facilitated the workshops with a classroom teacher collaborating.

During the material exploration session, the pupils explored materials through *material image cards*, *collage* and *matrices*. First, the pupils were requested to categorise seven different materials with fifty cards. Second, they were requested to select their four favourite cards and to describe the names, feelings and uses of the materials on the other side of the cards.

The pupils had been requested to collect materials from their surroundings as a pre-task before the exploratory sessions. These collected materials were displayed in the classroom before the session started. After the activities with the material image cards, the pupils explored the different materials, displayed in the classroom. They selected four different materials from which to make *material collages*. With the *material collages*, the pupils compared the different feelings of the materials, and placed them on material matrices on the wall. The teacher and the author guided and assisted the pupils with positioning their material collages on the matrices.

Case 3. Yeonhui Elementary School

The third case was conducted in Yeonhui Elementary School in Seoul, South Korea, in November 2014 and structured as a one-day design workshop lasting three hours. The pupils (n= 26, 14 boys and 12 girls) were Korean and mostly ten to eleven years-old in the fifth grade. The workshop was conducted in

Korean. The participants worked as individuals or groups (2 boy groups, 2 girl groups and 2 mixed gender groups) on different activities based on the author's instruction. She organised and facilitated the workshop, and the classroom teacher and one subject (English) teacher assisted in the session.

The pupils experienced different material study toolkits through diverse activities. First, the pupils explored different materials with *material image cards* and were requested to choose nine favourite materials and write those down in the *material palette sheets*. Second, the pupils then experienced tangible materials from the *sample kits,* as well as created four *material collages* and *material matrices*. Third, they used the *material building blocks* for the design of new buildings. The structure of the material study followed the first case. Compared with the previous case, a different format of the *material palette, material sample kits,* and *building blocks* were added in this project to enhance a more tangible material-experience.

Evaluation and findings

According to the children's ages and their material experience, the author applied different material study toolkits and evaluated them. Each approach revealed advantages and limitations, and some of them were utilised by only certain age groups. Overall, the younger children were interested in objects rather than substances; in contrast, the older children preferred fabricated materials with which they could build their own shapes. To reiterate, the purpose of this study was to evaluate material study approaches and toolkits with different age groups rather than compare the results between the respective cases.

Based on the preliminary research, some children in the range of seven to nine years-old had difficulties writing. Hence, the author employed a material frottage approach, which could be adapted to any child in this age group to experience various materials without the necessity for mature writing skills. In general, the children enjoyed making their own material collages after observing and selecting materials. Some children revealed a preference for certain materials, such as cardboard, metal or materials from nature. Furthermore, the boys had more interests in collecting different types of materials rather than focusing on certain types of materials. In addition, the younger children (ages 7-9 yrs.) selected more numerous materials; however, the older children (ages 13-19 yrs.) chose fewer materials for making collages.

With the material image cards, the children participated in distinctive activities: categorising material groups, selecting favourite materials, and describing the materials. This approach triggered in children a desire to talk about their previous knowledge of materials. Some children could not immediately select materials, even though they had previously experienced them. One issue that arose was the misinterpretation of a few images on the cards and the materials represented, or they were recognised differently according to each participant's understanding. The teachers commented that material image cards were relevant kits for material study; however, the children first recognised objects rather than materials on the cards. The teachers also commented on including material names on the cards since the children occasionally asked for the name of the materials which were unfamiliar to them. The original image cards were designed with names of each material; however, these had been removed to allow the children's imagination more free rein. For educational purpose, the names of materials will be more thoroughly considered later.

Handed-out materials are mostly used to encourage an interest in study in learning and teaching occasions. The *material palettes* had transitioned their forms from two-dimensional to three-dimensional. First, the children had difficulties filling out the two-dimensional *palette sheets* because of a lack of knowledge and experience of the materials. Later, the palettes also transitioned into three-dimensional forms as boxes with which to directly collect tangible material substances.

Through creating *material matrices* with the *material collages,* the children could practise comparing different qualitative tactile experiences of materials. The outcomes varied; namely, some materials were placed in different positions by different age groups. For example, cardboard was separately grouped based on variety of thickness, density, softness and hardness. These indicated how children understood materials in different ways.

A few participants commented that the material building blocks were one of the mostly excited and fun material study toolkits. Concerning the building blocks, most children could confidently construct models in a short period of time. These supported the children with rapidly and easily developing their ideas. In contrast, the teachers selected material sample kits as the most effective material study toolkit for children. The children directly experienced different materials with their hands. The purpose of the sample kit was to provide opportunities for a tangible material experience. Most children participated with great enthusiasm. Unfortunately, we lacked sufficient time in the workshops, thus, limiting opportunities for the author and children to share material experiences. Allocating more time will be needed in further studies to encouraging children to experience materials in various ways and sharing how to express their experience.

Overall, the young participants showed great enthusiasm in the projects and were satisfied with the material study. In the first case, many participants commented positively on how the material study was a departure from their ordinary lesson, and how it was useful to study the materials before starting design inquiries.

> *"I have been in the ARKKI class for many years, but we usually got the projects and immediately started to build. This material study was very useful for experiencing materials before starting a project." (Twelve years-old boy from the first case)*
>
> *"The material matrices were interesting. It was neither too difficult nor too easy." (Thirteen years-old boy from the first case)*
>
> *"It was nice to use different kinds of fabrics" (Eleven years-old girl from the second case)*
>
> *"I liked the project because you could do it yourself and no one said what you had to do." (Eleven years-old girl from the second case)*

Materials (substances and toolkits) support constructing ideas

The oldest group of children (13-19yrs) in the first case, were experienced participants with materials as well as designerly and architectural inquiries. Many of pupils have been attending for several years the architectural school, which was like an after-school activity. Occasionally, they have worked from sketching to modelling when they undertook projects. In this project, they were requested to explore different materials before they started to construct any models. Many participants commented that exploring materials was relevant for brainstorming new ideas and quick ways to appraise shape and strength of structure. They agreed that materials supported constructing and developing their ideas.

The children implemented similar materials from material collages in the material study session to building models in the implementation session (Figs 3 & 4). Compared to the oldest group, the children from younger age groups experimented with more diverse materials, even though they would not implement the same materials when they built models. This differentiation has shown that children's different ability to think intellectually is based on their ages.

Fig 3. One student explores different materials in the material study session.

Fig 4. The student applied the experimented materials to build models.

Materials (toolkits) invite participation in developing the curriculum

In general, all the participants expressed great enthusiasm about participating in the different activities during the projects. The provided materials triggered children's to their motivation and participation in the activities. These activities could be formulated as lessons in the primary school curriculum. The classroom teachers from the second and third cases mentioned that this whole project matched the aims and goals of multi- and cross-disciplinary as well as integrated curricula in comprehensive education in Finland and South Korea. The teacher from the second case stated that the workshop had multidisciplinary teaching and learning approaches, for example, arts, design, architecture, mathematics, geography, literature and English (Fig 5). She was pleased to have this type of teaching and learning process as well as approach. She incorporated this project into their curriculum, and she was able to teach pupils literacy (through creating stories), mathematics (through measuring), art (through drawing), crafts (through modelling), geography (through displaying on the map) and communication (through discussion) (Lee 2016).

Fig 5. This project integrated various subjects (e.g. arts, design, architecture, mathematics, geography, literature and English) in the primary school curriculum.

Materials (both) provide learning new knowledge and skills through practices

During the whole project, children learned through their own practice. The adults, both the design expert and classroom teachers, planned the contexts of projects, allocated space and time, as well as provided resources. Students initiated their design projects and made decisions with the guidance of the adults during the design process. In the material study session, participants could experience and explore different materials with their hands. The experimental activities helped children to understand about materials and structure, as well as to form their ideas into more tangible and feasible shapes (Fig 6 & 7).

Sometimes children experienced failure of their ideas; for example, some materials were not as flexible as expected.

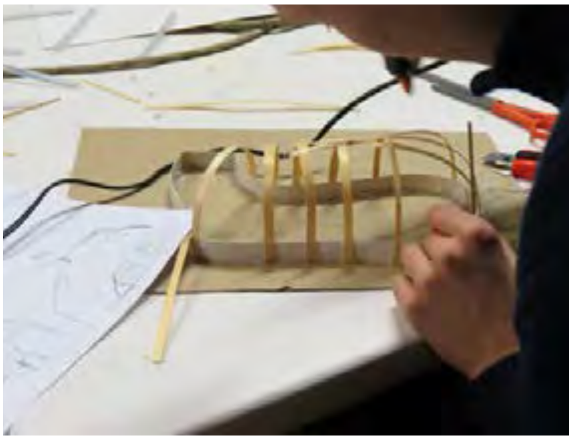


Fig 6. One child are building structure of an organic building out of wooden veneer.

Fig 7. One student has tested to build a polygon type of mock-up out of papers before initiating real prototype.

Children learned new knowledge and skills through practice. Then, the provided materials, both substances and study toolkits, were adapted to accelerate the learning. The design expert assisted the children in making their decisions using designerly and architectural techniques, including drawing to scale, finding suitable modelling materials, building the shape and structure, and installing the model. Hence, children's motivation was encouraged as their active participation in the projects.

Discussion

This material study approach supported multi- and cross-teaching and learning approaches. This could be integrated into diverse subjects in child education. However, the material study toolkits were selected and applied in different ways to the three studies; therefore, the evaluations were focused on the characteristics of the toolkits rather than comparing them with the collected data.

Based on the preliminary research of interaction and exploration between children and materials, this research introduced tactile material study approaches and toolkits to foster children's tactile learning and experiences. These provided children with tangible opportunities to learn designerly ways, the skill of solving problems and generating ideas (Figs 8 & 9). Moreover, these materials provide that designerly skills could be integrated into children's education. The five principles of the 'Designerly ways of knowing' were developed to work with children in this study:

- Children rapidly and easily tackled 'ill-defined' problems through the use of materials
- Children could experience problem-solving immediately by using the materials
- Materials helped the children's constructive thinking
- Children learnt to implement starting from an abstract requirement into concrete objects through materials
- Materials assisted children in presenting their ideas and thoughts.

The materials between a person and their surroundings help them to make sense of the world they experience. Adopting the notion of 'Material as a medium' (Kuusk, Wensvenn and Tomico 2016), materials can connect children and their world. These provide children opportunities to be aware of, to participate in, and to learn through tangible ways. Namely, materials support children to constructively develop their ideas, engage them to fully participate in their education, and teach new knowledge and skills to children through practice. During these interactions, designers facilitate the practice or activities to enhance more feasible communication between the children and the opportunities.

Figs 8 & 9. A student agilely initiated creating and developing their ideas and practiced problem-solving with provided materials (Lee 2016).

As a medium,

- Materials are alive to support children in developing their ideas.
- Materials are active in engaging children's participation in developing curricular.
- Materials are adaptive enabling children to learn new knowledge and skills through practice.

Conclusion

This study contributed to fostering children's material-experience in education. As a medium, materials supported children to rapidly and easily develop and express their ideas, to actively engage children's participation in their education, and to adaptively provide them with opportunities to learn new knowledge and skills through activities (practices) based on designerly ways of knowing.

This material study approach will be developed to enhance tactile experience in tangible toolkits in addition to digital formats. In particular, some of the activities in the material exploration session hold the potentials to be transformed into a web-based material study platform. Furthermore, this research provides evidence that material could be implemented as a medium to promise better communication and collaboration between adults (designers, researchers and educators) and children in the design process.

Acknowledgement

I would like to express my heartfelt appreciation to all of the students and teachers who participated in the projects.

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A new approach to materials in Product Design education - A shift from technical properties towards sensorial characteristics

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Abstract

This study evaluates a new pedagogic approach implemented in material courses for product design students at bachelor level education. Material education within the field of design education at technical faculties has, in general, a strong technical focus, e.g. selecting materials with predominant focus on engineering properties of materials. Product design education at a bachelor level need to offer material courses that prepares the design students to work both on inspirational and analytical levels in material selection processes. Early in the design education, students often have a preconception of materials, and they need to be introduced to an open-minded inspirational material selection process, based on scientific design methods. When developing a new curriculum for the material courses, it is important to teach materials and production methods in a contextualized setting with emphasis on how materials can be approached in a design process. Methods can be seen as mental tools that aids the design students in navigating complexity and offers them a structure to deal with unfamiliar territories. After an evaluation, we selected some methods, guidelines and tools to integrate in the mandatory material courses for the product design students e.g. the Expressive-Sensorial Atlas, Meaning Driven Materials Selection and the Material Driven Design method. The implementation were made in two steps in order to test, evaluate and further develop a framework for teaching materials courses to product design students. This study only reports the first step of implementation since the second step is under development and will be implemented during autumn 2017.

Keywords

Material Driven Design; Material education; Product design; Material selection; Teaching practice

This study evaluates a new pedagogic approach implemented in material courses for product design students at bachelor level. After a several-year long process of gathering knowledge, gaining experience and finalizing negotiations with involved stakeholders, we implemented a new curriculum in the fundamental materials courses that are mandatory for all Product Design students. The radical shift in how product design students are taught materials and manufacturing methods was possible after transferring Product Design education from the technical faculty to the design faculty.

At the beginning of the education, design students often have limited knowledge of materials and this knowledge is often based on personal experiences (Hasling & Lenau, 2014). The study indicates that activity-based or 'hands-on' learning, combined with scientific understanding of materials, improve the students' abilities to articulate and make informed decisions in a design process. Professional Designers are typically restricted by a well-defined palette of well understood materials that are readily available, affordable and accessible. With knowledge and a deep understanding of materials, it is possible to challenge the mechanics and manufacturing with intelligent solutions that otherwise may not be explored (Thompson, 2011).

Initial sections of this article present the dilemma of the product design education at the technical faculty. We then discuss the use of methods in design education and present a set of methods found in the reviewed literature on materials experience, material learning, material selection and tinkering with materials. We then outline the new pedagogic approach and its implementation in two steps in the product design education at bachelor level. We then discuss the radical pedagogic shift that occurred when implementing the new curriculum. Finally, we reflect on the benefits and drawbacks of our approach and suggest potential improvements.

Design education at technical faculties

Design education at technical faculties is often characterized by a curriculum for materials education with a predominant focus on technical properties. Due to long scientific and technological tradition, the engineering discipline has a well developed curricula for material education supported by textbooks, digital tools, etc. Effective communication of material knowledge and design knowledge between the two disciplines - material science and design - has proven to be challenging due to their different perspectives on materials. Engineering students, at bachelor level, study well-established textbooks with scientific knowledge that is 'unquestionable' and developed during the past two centuries (Bucciarelli, 2003). This kind of 'content knowledge' can be seen as static and difficult to apply in an open ended learning exercise typical for design students. Materials teaching is often pervaded by a tension between on one hand a natural scientific and engineering oriented topic and on the other hand, a design education rooted in the practice based and constructive tradition (Hasling, 2015). There is a tendency of 'watering down' the material education for design students, instead of using adequate, up to date scientific methods from the field of design to cover both the technical properties and sensorial characteristics (Asbjørn Sörensen, Warell, & Jagtap, 2016).

Design education at a tertiary level needs to offer material courses that prepare students to work both on inspirational and analytical levels in material selection processes. Early in the design education, students often have a preconception of materials, and they need to be introduced to an open-minded inspirational material selection process, based on scientific design methods. The authors' own experience suggests that students gain a deeper understanding of materials if the theoretical lectures on materials are closely linked to hands-on material experiments (Asbjørn Sörensen et al., 2016). By linking the theory and experiments in a project, preferably in the same course, students have the opportunity to apply their learning outcomes in a product development project, and this is "…effective in bridging the divide between 'knowledge about' and 'experience in' materials", as suggested by Pedgley, Rognoli and Karana (Pedgley, Rognoli, & Karana, 2015).

Method usage in design education

Methods can be seen as mental tools that aid the design students in navigating complexity and offers them a structure to deal with unfamiliar territories. Methods assist design students in skill development and to reinforce practice that is necessary for developing intuitive expertise over time (Kahneman & Klein, 2009). Reflection-in-action contributes to a reinforced practice by paying attention to and learning from decisions and actions that lead to mistakes or unexpected outcomes of method usage (Schön, 1983). Methods should not be seen as mere instructions to follow but rather as mental tools or mind-set to understand increasing complexity and to be able to contribute with qualified solutions (Hasling, 2015). A project portfolio can be a valuable tool when used in a reflective discussion with the students about their personal experience of method usage in a design process and can thereby contribute with an valuable learning experiences.

When developing a new curriculum for the material courses it was considered important to teach materials and production methods in a contextualized setting with emphasis on how materials can be approached in a design process. Experience from the old curriculum had indicated that when design students and engineering students were taught the same courses in material and production methods the courses tended to become too general and decontextualized. Design students are generally interested in applied materials and were often discouraged by the technical approach in the introductory courses. It became difficult for the design students to relate the purely technical aspects of materials to the applied material knowledge gained through the design projects. Early in the development of the new curriculum, it also became clear that it was important to make a distinction between material selection and material exploration, as they are two different ways of approaching materials (van Bezooyen, 2014). They are of equal importance but demands different methods and mind-sets. Material selection refers to the well-defined process applied in the later stages of a design process where the materials selection criteria are defined by context of manufacturing and cost to realize an already mature product concept. Materials considered in the fuzzy front end of the design process are dealt with at a more abstract and holistic level, e.g. creating a material vision instead of defining materials requirements for product realization. This could contribute to strengthen the abilities of design students to integrate their material knowledge and skills in the design process, from the fuzzy front end to the structured back end in a professional setting.

Inventory of methods

A literature review was carried out with focus on guidelines and tools used in or developed for materials education in the field of design (Asbjørn Sörensen et al., 2016). The following methods, guidelines and tools were integrated in the existing material courses for the product design students.

The Expressive-Sensorial Atlas

The Expressive-Sensorial Atlas uses four parameters, namely texture, touch, brilliancy and transparency (Rognoli, 2010). The charts provide illustration of sensorial qualities using a sample of materials combined with a simple, concise textual definition. Design students rank material samples, based on personal sensation that result in a subjective and qualitative sensorial scale (fig.1a) from one sensorial extremity to another e.g. light-heavy. The subjective sensorial maps trigger relevant discussions between the students when they realize that the result do not always correspond to the scale derived from objective material measurements. In fig.1b, the product design students were asked to rank ten material samples from light to heavy, first subjectively and then according to density.

Fig 1a. Property explanations and physical samples combined into the Expressive-Sensorial Atlas and developed into a scale of light/ heavy (Rognoli, 2010). 1b. Material samples ranked from light to heavy by product design students, first subjectively and then according to density, in the top row.

Meaning Driven Material Selection

Meaning driven materials selection, MDMS, (fig.2) aims to assist designers in manipulating meaning creation in materials selection (Karana, Hekkert, & Kandachar, 2010). The model offers a multifaceted framework that embraces both sensorial characteristics as well as technical properties that are embedded in a material. The guidelines help students to understand how the complex combination of manufacturing methods, shape and function relates to the user experience defined by, for example, expertise, gender, age, and cultural background.

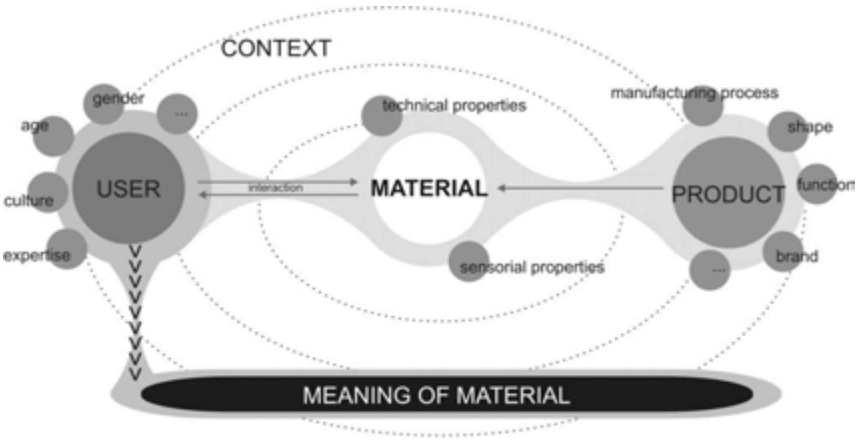

Fig 2. Meanings of Materials Model (Karana et al., 2010).

Hodgson and Harper

Hodgson and Harpers guidelines (fig.3) offers an overview of how a range of 10 *materials related product attributes* contribute to the realisation of Form, Function and Fabrication in a product. These in turn ultimately determine both the cost and value of the product, which must ultimately match the need or market (Hodgson & Harper, 2004). The guidelines support the design student in exploring the potential and consequences of each attribute in relation to the surrounding attributes as well as the need and context. By integrating cost and value, it reflects a realistic scenario that could support professional designers as well. Reflection is crucial in a material selection process since there is no specific answer; only contextually related material candidates that offer different solutions. The guidelines are developed as a reaction to how material selection is traditionally taught in design education.

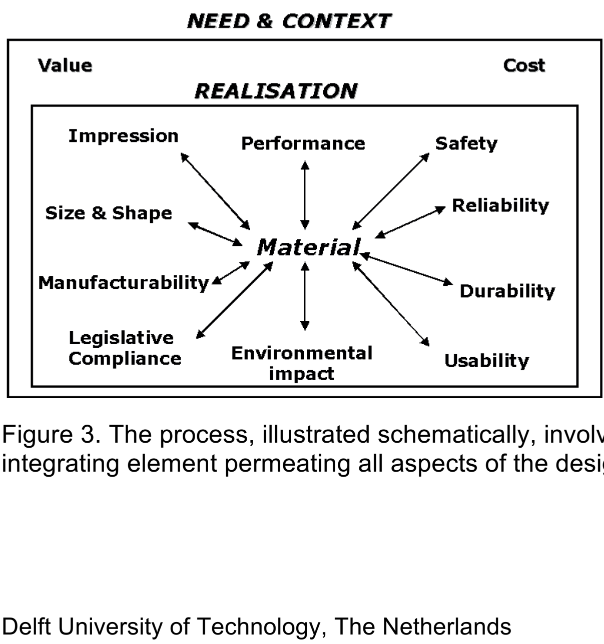

Figure 3. The process, illustrated schematically, involves putting the materials at the heart of the design process, as the integrating element permeating all aspects of the design (Hodgson & Harper, 2004).

The CES-EduPack

The Cambridge Engineering Selector, CES EduPack, developed by Granta for design engineering is based on the work of Ashby and Cebon (Granta Design, 2016).The CES-EduPack offers material selection based on technical properties, manufacturing processes, environmental and sustainability aspects. The program offers visualizations and material charts of technical properties. The material charts can preferentially be used in combination with other tools in the design education to explain the complex relations between technical properties and intangible characteristics.

The 2016 version of CES-Edupack offers a new beta-version database for engineers and industrial design students called the Products, Materials and Processes database (fig.4). The database is product-centered and contains descriptions and data of materials and processes used to make products. The product examples are intended to act as de-codifiers between intangible characteristics and technical properties (Granta Design, 2016).

Figure 4. Example of datasheets from CES-EduPack 2016 Database Products, Materials and Processes. The first datasheet describes the product Cylinda line Hot by Arne Jacobsen, the second and third describes the material stainless steel used in the product (Granta Design, 2016).

Material Driven Design

The Material Driven Design (MDD) Method facilitates design processes in which the materials are the main driver (fig.1). The MDD-method encourages hands-on interaction with the material at hand, from the first encounter through to exploring and understanding the material in detail with its unique qualities and limitations (Karana, Barati, Rognoli, & Zeeuw van der Laan, A, 2015). By working with an explorative approach, the designer understands the material in depth e.g. experiential qualities, physical properties and '*the material's purpose within a situational whole'*. The MDD-method guides the design student in a journey from material properties and experiential qualities to materials experience vision, then to experiential qualities, material properties and finally to products. Activities to support this journey are organized under four main steps as: (1) Understanding the Material: Technical and Experiential Characterization, (2) Creating Materials Experience Vision, (3) Manifesting Materials Experience Patterns, (4) Designing Material/Product Concepts.

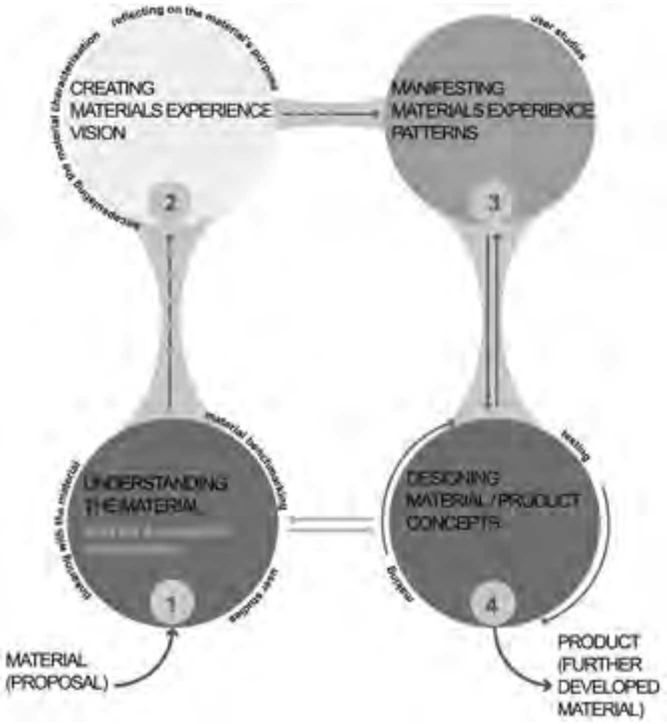

Fig 5. Action steps in the MDD-method (Karana et al., 2015).

In order to create a meaningful application, designers need to move from material characterization to a holistic vision (Step 2 of MDD). They also need to enable novel experiences by crafting the vision into a meaningful application (Steps 3 and 4 of MDD).

The MDD-method can be used in different scenarios and Karana et al. suggest the following scenarios:

1. Designing with a relatively well-known material. Although the material is likely to have some settled meanings in certain contexts the designer seeks new application areas to evoke new meanings and to elicit unique user experiences.
2. Designing with a relatively unknown material, which will be accompanied by a fully developed sample (e.g. liquid wood, D3O, thermochromic materials, etc.). The material is unlikely to be linked to established meanings, giving the designer an opportunity to define application areas through which unique user experiences, identities for materials, and new meanings may be introduced.
3. Designing with a material proposal with semi-developed or exploratory samples (e.g., food waste composites, living materials made of bacterial cells, 3D printed textiles, flexible OLEDs, etc.). Since the material is semi-developed (i.e., proposal), its properties are to be further defined through the design process in relation to a selected application area, also to generate feedback for further materials development (e.g., elasticity of a food-waste composite, durability of a 3D printed textile, etc.). Furthermore, since the material is novel, it is difficult to recognize and is in need of the designer to propose meaningful applications through which unique user experiences and meanings will be elicited.

Implementation of design methods

A several-year long process of gathering knowledge, gaining experience and finalizing negotiations with involved stakeholders made it possible to implement a new curriculum in the fundamental materials courses that are mandatory for Product Design students. How does one then implement the methods found suitable for the materials courses in the Product Design bachelor programme? The first step of implementation was made in the existing materials courses, without changing the learning outcomes in the course syllabus, instead literature, methods, tools and the pedagogic approach was updated. By doing it in two steps it was made possible to test, evaluate and further develop a framework for teaching materials courses to the product design students. The second step of implementation has been to restructure the Product Design bachelor programme and write new course syllabuses. This study only reports on the first step of implementation since the second step is under development and will be implemented during Autumn 2017.

Applied materials and tools for model making in Product Design 15ECTS

The course *'Applied materials and tools for model making in Product Design'* (last course in the 1st year) has been given with the same course syllabus since spring term 2012 (fig.6). Product Design has been responsible for the planning and execution of the course and Material Science have offered the same series of lectures for students from product design and mechanical engineering since 2007.

<table>
<tr><td>W 1</td><td>W 2</td><td>W 3</td><td>W 4</td><td>W 5</td><td>W 6</td><td>W 7</td><td>W 8</td><td>W 9</td><td>W10</td><td>W11</td><td>W 12</td><td>W 13</td><td>W 14</td><td>W 15</td><td>W 16</td><td>W 17</td><td>W 18</td><td>W 19</td><td>W 20</td></tr>
<tr><td colspan="9">Materials: theory (material families, technical properties, materials and production methods).</td><td colspan="2">Mechanics of materials: theory</td><td colspan="9" rowspan="4">Design project: Design a handheld consumer product with a basic function in two materials. (Technical drawing, 3D-modelling, modelmaking, materials selection process.)</td></tr>
<tr><td colspan="4">Workshop driver's licens part 1 & 2</td><td colspan="4"></td><td>Materials: applied</td><td colspan="2"></td></tr>
<tr><td colspan="11">3D-modelling: SolidWorks</td></tr>
<tr><td colspan="5">Technical drawing: theory & applied</td><td colspan="6"></td></tr>
</table>

Figure 6. '*Applied materials and tools for model making in product design*' 2012-2015.

The lectures were criticized by the engineering students for being too general, not theoretical relevant enough and 'moving forward too slow'. The design students found on the other hand the lectures 'too theoretical', not able to link the lectures to other learning activities in the courses and 'moving forward too fast'. The reasons for giving the same series of lectures were a well-established practice in the technical faculty and the financial benefit of joint studies. The theoretical parts of the material courses examined in written tests were often criticized for not evaluating the students' ability to link theory to applied design problems. Knowledge in this form can be considered static, included in a textbook and stored in memory to be recalled at the time of the exam, not allowed to be considered as an active, creative knowledge production of the moment (Bucciarelli, 2003).

When restructuring the course the main goal was to facilitate knowledge creation in the intersection of theory and hands-on material experience. The difficulty in a multidisciplinary teaching environment was that different members of teaching staff have been trained in different research paradigms. It was a prerequisite to succeed that all involved teachers in the course had a common vocabulary and an understanding of the methods and guidelines introduced, not only the ones they taught themselves. Material Science chose not to offer new lectures for the design students but assisted instead the design teachers in developing a new lecture series. The lectures were developed in the spirit of active learning (Felder & Brent, 2009) with brief interludes of practice and feedback to offer the students an understanding of the more complex context of, for example, the relation between technical properties and sensorial characteristics. The Expressive-Sensorial Atlas (Rognoli, 2010) was introduced and used during the lectures as a way for the students to explore the relationship between what is perceived subjectively and what is measured objectively (fig.1). The content of the lectures were also adapted to design students' pre-knowledge of materials and developed to reflect the latest research in the design and materials domain. The number of commercial materials available is rapidly increasing and the traditionally used taxonomy of material families is gradually decomposed with hybrid materials such as composites. Therefore, it is fundamental to provide students with tools to create their own understandings of materials (Hasling & Lenau, 2014).

<table>
<tr><th>W 1</th><th>W 2</th><th>W 3</th><th>W 4</th><th>W 5</th><th>W 6</th><th>W 7</th><th>W 8</th><th>W 9</th><th>W10</th><th>W11</th><th>W 12</th><th>W 13</th><th>W 14</th><th>W 15</th><th>W 16</th><th>W 17</th><th>W 18</th><th>W 19</th><th>W 20</th></tr>
<tr><td colspan="2"></td><td colspan="4">Materials: theory (material families, technical and sensorial properties, material selection methods, materials and manufacturing methods).</td><td colspan="3"></td><td colspan="2">Mechanics of materials: theory & applied</td><td colspan="9" rowspan="3">Design project: Design a handheld consumer product with a basic function in two materials. (Technical drawing, 3D-modelling, modelmaking, materials selection processes.)</td></tr>
<tr><td colspan="4">Workshop driver's licens part 1 & 2</td><td colspan="7">Materials: applied in the workshop. The same object replicated in different materials and manufacturing methods (metals, wood, polymers, textile, ceramics). Written reflection: results, challenges and learning outcomes. Technical drawings of each finished object.</td></tr>
<tr><td colspan="2">Technical drawing: theory & applied</td><td colspan="9">3D-modelling: Solid Works</td></tr>
</table>

Figure 7. '*Applied materials and tools for model making in product design*' 2016.

By restructuring the course (fig.7), the interaction between theory and hands-on learning were put in the centre, as we believe the students gain a deeper understanding of materials if the theoretical lectures on materials are closely linked to hands-on material experiments. In practice that could be a lecture on the material family of metals in the morning followed by working with tube bending and welding in the workshop later in the day. The students were given a material and manufacturing assignment were they was asked to replicate the same object in four different materials (metals, wood composites, polymers, textiles or ceramics). The students received a technical drawing of the original object with instructions to choose the most suitable technique for each material. When finalising the four objects the students should analyse each object using the Meanings of Materials Model (Karana et al., 2010) and compare the results in a seminar. New technical drawings of each object was produced and the students were asked to reflect on the complex combination of manufacturing methods, shape and function and how it relates to the user experience together with the teachers. The Mechanics of Materials were developed by a teacher from Material Science, from being a combination of lectures and theoretical calculations, into lectures and an applied two-day workshop were the students were asked to build constructions and put load on until they collapsed and the elaborate on the result. Second part of the course the students were given a design project were they applied their newly acquisitioned experience in and knowledge about materials in a design process. Simple causative or one-to-one relationships between materials, products, sensorial experiences, meaning attribution and emotional responses do not exist. Effective teaching and learning in this area must expose students to the complexity of contextual issues, whilst emphasising that with complexity comes richness in diversity and novelty (Pedgley et al., 2015).

Materials and production methods 15ECTS

The course *'Material and Production methods'* (1^{st} course 2^{nd} year) had the same historical background as the previously described *'Applied materials and tools for model making in Product Design'*. After experiencing mainly positive effects of the new pedagogical approach a radical change was implemented by introducing Material Driven Design (Karana et al., 2015) and Flipped Learning (Network,

2014) as key components in the second mandatory materials course *'Material and Production methods'*. In the traditional teacher-centred model, the teacher is the primary source of information. By contrast, the Flipped Learning model deliberately shifts instruction to a learner-centred approach, where in-class time is dedicated to exploring topics in greater depth and creating rich learning opportunities (Network, 2014). The Flipped Learning model was chosen as it actively involves the students in knowledge construction as they participate in and evaluate their learning in a manner that is personally meaningful. The pedagogic approach harmonizes well with the experimental and explorative spirit of the MDD-method. The students were introduced to the theoretical framework of Material Driven Design in a series of seminars where the class became a part of structuring the MDD-activities and timelines in the course (fig.8). It is important to encourage students to work explorative and also learn from failures in the iterative process of tinkering with materials and as a consequence create a certain degree of flexibility in the timeline. The students were asked to apply the MDD-method to material proposals that were semi-developed/exploratory (textile waste and coffee ground) or with a relatively unknown (mycelium). Learning to investigate a material in an explorative yet structured way increased the integration of material thinking in the design process and made the design students reflect on the materials they use.

<table>
<tr><th>W 1</th><th>W 2</th><th>W 3</th><th>W 4</th><th>W 5</th><th>W 6</th><th>W 7</th><th>W 8</th><th>W 9</th><th>W10</th><th>W11</th><th>W 12</th><th>W 13</th><th>W 14</th><th>W 15</th><th>W 16</th><th>W 17</th><th>W 18</th><th>W 19</th><th>W 20</th></tr>
<tr><td colspan="2">MDD: Theoretical background</td><td colspan="4">MDD: Develop a material proposal</td><td colspan="4">MDD: Creating a material experience vision</td><td colspan="10" rowspan="2">MDD: Manifesting material experience patterns. Designing material/ product concepts.</td></tr>
<tr><td colspan="4">Materials: theory (materials & production methods, technical & sensorial properties, material selection methods)</td><td colspan="2">Production economy: theory & applied</td><td></td><td colspan="3">Mechanics of materials: theory & applied (testing the materials produced in the MDD-project)</td></tr>
<tr><td colspan="2"></td><td>Field trip to manufacturers</td><td></td><td colspan="8">3D-modelling: SolidWorks</td><td></td><td colspan="3">Rapid prototyping: theory & applied</td><td colspan="4"></td></tr>
</table>

Figure 8. *'Material and Production methods'* 2016.

The MDD-method became integrated in the course structure so that the different learning activities supported each other, e.g. the pull test (fig.9) in the applied mechanics of materials module was performed on the material samples (fig.10) the students produced in the course. The benchmarking of materials became connected to the methods used in the production economy module and so forth.

Figure 9. Material samples produced by one group of students in the course *'Material and Production methods'* 2016 followed by a pull test of the final sample.

Figure 10. Material samples developed from textile waste by students. Cotton fibers mixed with a tapioca based polymer.

Working with the different steps of the MDD-method in a course structure is rewarding but challenging for both teachers and students as it demands good communication between everybody involved or else some of the synergies in learning activities are lost. We would like to suggest that parts of the MDD-material are further developed, e.g. the pictures used for the experiential characterization, creating instructional material for teachers so that more design students could benefit from the method.

Discussion and conclusions

This study has offered the opportunity to reflect on the didactic approach to materials teaching in product design. The challenges of applying a new pedagogical approach to an existing course syllabus rendered mainly positive experiences. After implementing the new pedagogic approach and methods Material Science has shown interest in developing their own material courses for the mechanical and material engineering students. The field of engineering, especially related to materials, could benefit from adapting these methods into their material education. It could contribute to a more efficient understanding of the sensorial characteristics that are linked to the technical properties. It could also contribute to less miscommunication between engineers, designers and non-technical professions in the product development process, often characterized by a multi-disciplinary work. Materials constitute the physical appearance of a product, and choosing the right materials is fundamental for, how a product will function and how it will appear. As part of the product design education, students have to develop a material practice that incorporates material thinking in their overall design practice and this includes how materials are evaluated and selected (Hasling & Lenau, 2014).

The results so far indicate that the students have gained better understanding of the complex context of material related activities in a design process. There is a tendency of greater variation of relevant material candidates in the design projects instead of the ‘usual suspects’. Sustainability has surprisingly become a naturally integrated part of the materials courses and is no longer treated as a separate attribute but have instead become embedded in the design process. The students developed their material vocabulary during the courses, contributing to a higher quality and precision in the discussions. We hope that this study can inspire to introduce Material Driven Design in more design educations.

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Sustainable materials in design projects

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Abstract

New types of sustainable materials are introduced in our markets every year to minimise the environmental impact of products. The search for more environmentally benign materials is crucial in reducing the depletion of non-renewable material resources. Recent literature indicates that there is a growing interest and rapid technological progression from various industry stakeholders on this matter. Nevertheless, the sustainability issues pursued by designers and other material developers are still ambiguous. The overall aim of this research is to develop new understanding of the sustainable materials being developed and applied in product design. Seventy-two material-centred design projects are analysed in terms of resource renewability and resource origin. The data obtained are further classified according to the material group and products produced with such materials. Renewable materials make up half of the materials used. Moreover, waste materials comprise up to half of the materials used. Three materials groups were found to be more frequently used, namely natural composites, synthetic polymers and organic materials. Most of these materials are being made into furniture, household objects and clothing and accessories. Within the natural composites and organic materials, various extraordinary materials were used, reflecting the dynamicity of designers' work and experimentation with materials. As for synthetic polymers, recycled plastics are the main materials used and this is not surprising given their abundance in the environment. In general, the application of sustainable materials seems to be at its infancy but explorations are vibrant and progressive. The impact of these materials in the mainstream market is unknown and other sustainability factors need further evaluation. As such, design as a discipline is yet to facilitate the uptake of these materials.

Keywords

Sustainable materials, sustainable design.

Every year millions of products are sent to landfills due to a throw-away culture. This rate of consumption will continue to grow, thus putting a strain on material resources and the environment (OECD, 2013). As a result, product developers have a growing interest in moving towards use of sustainable materials. Current initiatives to introduce sustainable materials are still in their early days with sustainability principles only starting to affect product development strategies. At a consumer level, while there is evidence that purchase decisions are influenced by companies' commitment to positive environmental impact, information made available to consumers on environmental friendly products remains limited and ambiguous (Brécard, 2014). For example, emphasis is placed on environmental and social attributes of products but the actual scientific proof of many claims is unknown (Hoek, Roling, & Holdsworth, 2013). Further to this, in a material context sustainability is dependent on many factors, which make any argument about the sustainability of materials complicated.

This research aims to characterise sustainable materials used in design projects and explore what products are being made with them. The results of this research reveal the breadth of materials developed and applied. The characterisation of materials proposed in this research is useful to improve the quality of the discussion on sustainable materials and particularly the sustainability argument made. Furthermore, this research helps identify distinct efforts to overcome the depletion of non-renewable materials and reflect on the emphasis and attention that these should be given.

Materials and sustainability

While global resources are further stressed by a push for faster consumption of short lifespan products (Rivera & Lallmahomed, 2015; Agrawal, Kavadias, & Toktay, 2015) and the rapid growth of developing countries (Fiksel, 2006) sustainability concerns remain in the fore. As Miller (1972) highlights, the critical boundary of resource consumption is beyond the shortage of reserve and includes the adverse impact on the environment. The sustainable use of resources (i.e. materials) then needs to be addressed if we are to realise the vision presented in the Brundtland Commission's report *Our Common Future*, in which current use does not adversely affect future generations (World Commission on Environment and Development, 1987).

The central theme of materials and sustainability is to minimise the adverse impact of materials to humans and the environment through well-planned management. However, even defining sustainability can be complicated since it is dependent on multiple stakeholders' views and contexts (Arroyo, Tommelein, & Ballard, 2016). For instance, the meaning materials convey changes with use and can lead to less favourable consumer appraisals or behaviours in terms of sustainability (Baxter, Aurisicchio, & Childs, 2015, 2016). It is also often too simplistic to regard certain materials as (un)sustainable as perfect data on the reserve of non-renewable materials is often difficult to obtain (Graedel et al., 2012). The result has been the development of several objectives and guidelines to move toward more sustainable use of materials. McDonough and Braungart (2002) have emphasised the need to manage material resources through efficient lifecycles including closed-loop processes in which waste is avoided. Ashby and Johnson (2010) have placed a time to this management suggesting that the timescale of sustainability concern should be fifty years into the future . Achieving these objectives is aided by the concepts of detoxification and dematerialization. Detoxification describes the attempt to reduce toxic materials used in material production or manufacturing processes, which includes the use of renewable resources for chemical substance (Weenen, 1995). Dematerialisation is concerned with the substitution of virgin materials with recycled materials, (Fiksel, 2006) and resource intensive materials with sustainably harvested and renewable materials (OECD, 2010) .

Assessment of sustainable materials is aided by several metric based tools that have emerged such as life cycle assessment and ecological footprinting (Robèrt, 2000). Typical considerations are environmental impact, resource efficiency, waste minimisation, life-cycle cost and performance capability. Some industries move beyond assessments to also place labels on products to try to communicate various types of sustainable solutions. For example, the textile industry features a host of eco-labels including: compostable, degradable, designed for disassembly, extended product life, energy recovery, pre or post-consumer materials, recycled materials, reduced energy, reduced water consumption and reduced use of resources (Targosz-Wrona, 2009).

Sustainable materials exploration

Designers are continuously tinkering to expand their knowledge and find new materials and manufacturing processes. In recent years, this activity includes the exploration of sustainable materials. This work is partly driven by the democratisation of knowledge and production technology (Rognoli, Bianchini, Maffei, & Karana, 2015; Mota, 2011) the output of which is an increasingly large category of 'DIY' materials (Rognoli et al., 2015). This is further facilitated through maker communities

(Thilmany, 2014). Importantly material research is not limited to self-exploration, as multidisciplinary knowledge sharing platforms (e.g. the open workshops on bio-materials held by the Co-Lab at the Institute of Making, University College London) are also contributing to the dissemination of materials knowledge to the public.

Within design, materials with sustainable credentials are variously referred to as environment-conscious materials (Utsugi, Yiyin, Abe, & Shiraishi, 2007), materials with high sustainable potential (Rognoli, Salvia, & Levi, 2011) and eco-sensitive materials (Karana & Nijkamp, 2014).The difference between these terms is not always clear but the breadth of these terms is not altogether surprising since the area of sustainable materials is growing and is still divergent in thinking. Consolidating current work in this area into a general term in order to better understand the types of materials considered sustainable is central to the aim of this work.

One prominent theme found in the literature is the utilisation of abundant waste materials in new forms. Examples of this include: discarded wet blue leather remainders in the huge leather industry in Brazil used to produce oven gloves (Júnior, Cândido, & Guanabara, 2008); clay soil from rural areas in Spain used to make unfired-bricks for the construction industry (Miqueleiz et al., 2012); and *xylan* and *mannan*, widely available from the side-streams of agriculture and forestry and used to make sustainable packaging products (Mikkonen & Tenkanen, 2012).

The use of unconventional materials with peculiar surface characteristics in which imperfection is embraced and considered an appealing aesthetic is another emergent theme. Examples of such projects are: Tomas Gabzdil Libertiny's bees hive vase (Parsons, 2009); Suzanne Lee's bacterial cellulose jacket; Gingers Krieg Dosier's microbial-induced bricks (Ginsberg, 2014); a tissue-cultured jacket (Catts & Zurr, 2014); and seeds' tablets and pots based on coffee waste, which were designed using a tool known as Material Driven Design (Karana, Barati, Rognoli, & Laan, 2015).

Another theme is the exploration of living materials, i.e. materials embodied in products which possess additional 'interactive' features. These materials are often called smart materials as they sense and respond to environmental stimuli in a predicted manner (Tao, 2001; Stamhuis, 2015). Living materials are unique since they benefit from how the 'living' features contribute to additional facets of sustainability. Examples include: the oxygen-breathing 'silk-leaf' by a Royal College of Art graduate (Melchiorri, 2014), responsive bacterial based 'bio-skin' fabric by MIT Media Lab (Biologic, 2015), and bacterial mineral precipitation 'self-healing' concrete by TU Delft (Jonkers, 2007). The future of everyday living with these interactive materials or products that mimic living organisms were speculated by Johanna Schmeer from the Royal College of Art in a project called Bio-plastic Fantastic (Schmeer, 2014).

Research methodology

The literature review provided useful insights on the vast spectrum of sustainable materials explored by designers. In order to fulfil the aim of characterising sustainable materials, material projects were analysed and classified. This section presents information about the dataset of materials collected during this research and explains how the data was analysed and classified.

Data collection

Seventy-two material-centred design projects were collected from various sources including design websites and design fairs. Projects were selected for consideration if they had: i) a focus on sustainability; ii) an objective to research and implement a sustainable material; and iii) a goal to output a consumer product. For each project, the following information was collected: material, end-product produced, and developer. Materials ranged from creative explorations to industry-led projects. Products included both semi-developed and commercial objects. Developers included academia, designers, start-up companies and established companies.

Results

The materials in the data set were classified into three categories, namely resource renewability, resource origin and material group, see Table 1. The resource renewability category distinguishes if a material is from a renewable, non-renewable or semi-renewable source. The resource origin category characterises if a material is from a virgin or waste resource. The material group category classifies materials in five types, namely organic, bio-polymer, synthetic polymer, natural composite, and synthetic composite. This category, initially informed by the work of (Ljungberg & Edwards, 2003), has evolved following a data-driven approach, in which data was analysed to identify patterns and classes have emerged based on the data interpretation. The two composite material classes deserve a special note to explain how materials have been assigned to them. In a composite the matrix material surrounds and supports the reinforcement material by maintaining their relative positions. Typically, the matrix material is significantly higher in volumetric percentage than the reinforcement material, and therefore it affects more its sustainability. On this basis the distinction between a natural composite and a synthetic composite was made depending on whether the matrix is from a natural or synthetic material.

Category	Class	Definition	Example
Resource renewability	1. Renewable	Material made from natural organic resources.	Bio-plastic from corn starch, bacterial cellulose based material etc.
	2. Semi-renewable	Material made from two or more constituent materials of which at least one is renewable.	Wood wool and cement composite, bio-plastic reinforced fiberglass composite, etc.
	3. Non-renewable	Material made from a finite natural resource.	Synthetic polymer from petroleum, etc.
Resource origin	1. Virgin	Material made from a resource that has not been previously used or consumed.	Bamboo, wood plank, etc.
	2. Waste: by-product	Material made from waste that is a left-over of a production process.	Pineapple leave fibre-based material, agriculture residue, etc.
	3. Waste: second life	Material made from waste that is obtained from a product which has reached its end of life.	Expired meat, spoiled milk etc.
Material group	1. Organic	Material derived from biological substances.	Wood, cotton, bio-film, etc.
	2. Bio-polymer	Polymer-based material derived from biological substances.	Bio-plastic from plant cellulose, bio-plastic from corn starch, etc.
	3. Synthetic polymer	Man-made polymer from artificial components.	Polyethylene terephthalate (PET), high density polyethylene (HDPE), etc.
	4. Natural composite	Material formed by the combination of natural or synthetic reinforcement and natural matrix.	Natural fibre reinforced bio-polymer, e.g. composite of hemp fibre and bio-resin; natural fibre reinforced organic material, e.g. composite of wood and mushroom; natural fibre reinforced inorganic material, e.g. composite of natural fibre and clay; synthetic fibre reinforced bio-polymer, e.g. carbon fibre reinforced bioplastic.
	5. Synthetic composite	Material formed by the combination of natural reinforcement and synthetic matrix.	Natural fibre reinforced synthetic polymer, e.g. composite of cotton yarn and resin.

Table 1. Sustainable material categories

The products were also classified into categories including: furniture, household object, clothing and accessories, packaging, building material, and others, see Table 2.

Household objects	Packaging	Furniture	Clothing & accessories	Building Materials	Others
Plate, mug, bowl, pot, clock, toothbrush, vase, basket, mat, toys, hoover.	Bottle, plastic bag, void fill packaging, fruit-carrier bag, razor packaging.	Stool, chair, bench, lighting, side table, table, outdoor seating.	Dress, shoes, textile, dress, necklace, sneaker, bag, sunglass.	Acoustic panel, bricks, tiles, flooring.	Musical instrument, car interior finish, surfboard, 3D printer filament.

Table 2. Product categories

Sustainable materials classified

The materials used in the data set were mapped according to the previously introduced categories, see tree in Figure 1. The numbers in brackets along the branches of the tree represent the frequency of the materials in the dataset in term of actual instances. At the bottom of the tree, material percentages for the classes of each category are provided.

The classification includes three main branches, which follow the classes of the resource renewability category. Results show that 50% of the materials are renewable, 18% semi-renewable and 32% non-renewable, see Figure 1. The classification further splits materials into sub-branches dependent on the resource origin category. This shows that 42% of the materials are virgin, 50% waste, and 8% a mix of virgin and waste. Waste can be a by-product of a consumption process, or a material which can have a second life. Finally, the classification identifies five material groups (see Figure 1) the largest of which are: natural composites (35%), synthetic polymers (29%) and lastly organic materials (18%).

The first branch of the classification is ‘renewable materials’. Within this*, virgin* materials lead to organic materials (9), bio-polymers (4) and natural composites (10). An example of an organic material is cork leather. Examples of bio-polymer and natural composite are plastic from corn-starch and a natural fiber composite from hemp, respectively. *By-products waste* materials lead to organic materials (3) and natural composites (4). Fibre from pineapple leaves is an example of organic material, whereas a composite of wood shave and a bio-resin is an example of a natural composite. *Second life waste* materials consist of organic materials (2), natural composites (3), and bio-polymers (1). Examples of these are expired meat, a composite of coffee waste and a natural binder, and plastic from spoiled milk, respectively.

The second branch is ‘semi-renewable materials’. Within this branch, *virgin-virgin composite* materials lead to natural composites (7). An example is a composite of eco-cement and hemp fibre. *Virgin-waste composite* materials are further split into materials with a *by-product waste* and *second life waste*. *Virgin-by product waste* materials lead to synthetic composites (2). An example is denim offcut from manufacture and resin. *Virgin-second life waste* materials consist of natural composites (4) and an example is a composite of bacteria, urea, sand and calcium.

The third and last branch is ‘non-renewable materials. Within this branch, *second life waste* materials lead to synthetic polymers (21) and synthetic composites (2). An example of the first material type is weaved seatbelt and discarded fabric and resin is an example of the second material type.

The five material groups, namely organic materials, bio-polymers, synthetic polymers, natural composites and synthetic composites, are now examined.

<u>Organic materials</u>: this group includes virgin materials from plants and extraordinary examples of utilised waste including second life materials such as expired meat and by-product materials such as

salmon skin and pineapple leaves. Some of these materials have an established process to convert them into products (e.g. salmon skin leather, bamboo), whereas others are still at conceptual level and require further research before the materials can be considered fully developed and feasible for commercial production (e.g. mycelium mushroom fabric, beetle's chitin film).

Bio-polymers: this group includes plastics from virgin renewable resources such as corn starch. Some of these materials are already in the mainstream market, were sourced from companies with high-tech production technology and used as surrogate materials. The complexity of polymeric materials and the constraints of manufacturing facilities seem to hinder designers' exploration thus making these materials among the least used. Still, there are early attempts to develop new bio-polymers from second life waste materials such as spoiled milk.

Synthetic polymers: recycled plastics make up the largest share of this group. This is expected since plastic waste from consumer goods is often abundantly available. Some of the plastics were reused, whereas others were recycled, i.e. they were broken down into their raw state and reprocessed into new products. The former type requires that technical properties such as rigidity are utilisable. As for recycled plastics, the production process requires uncomplicated procedures, compatible with existing plastic production methods thus providing ample opportunity for self-explored small scale production. For instance, high-density polyethylene (HDPE) bottle were converted into new products with self-made extrusion and injection moulding.

Natural composites: waste is the dominant origin of the resources used in this group. Among natural composites, there are predominantly natural fibre reinforced bio-polymers. However, natural composites were found to also include natural fibre reinforced organic materials, natural fibre reinforced inorganic materials, and synthetic fibre reinforced bio-polymers. The reason for this variety of composites is the ease of production of these materials. As such, many unusual materials were utilised within this material group, e.g. seaweed, algae, urea, manure etc. Several applications tend towards creative expression in which the combined materials were explored for new aesthetics as much as improved utility.

Synthetic composite: materials in this group are predominantly by-product waste and second life waste materials. In terms of production, these materials require simple procedures similar to the aforementioned natural composites. They are mostly post-industrial and post-consumption products that were combined with industrial resin. These materials are the least used in the dataset indicating that a bio-based matrix is typically the preferred option. Several applications portray the reinforcement materials in their original and unprocessed state, creating unique surface properties.

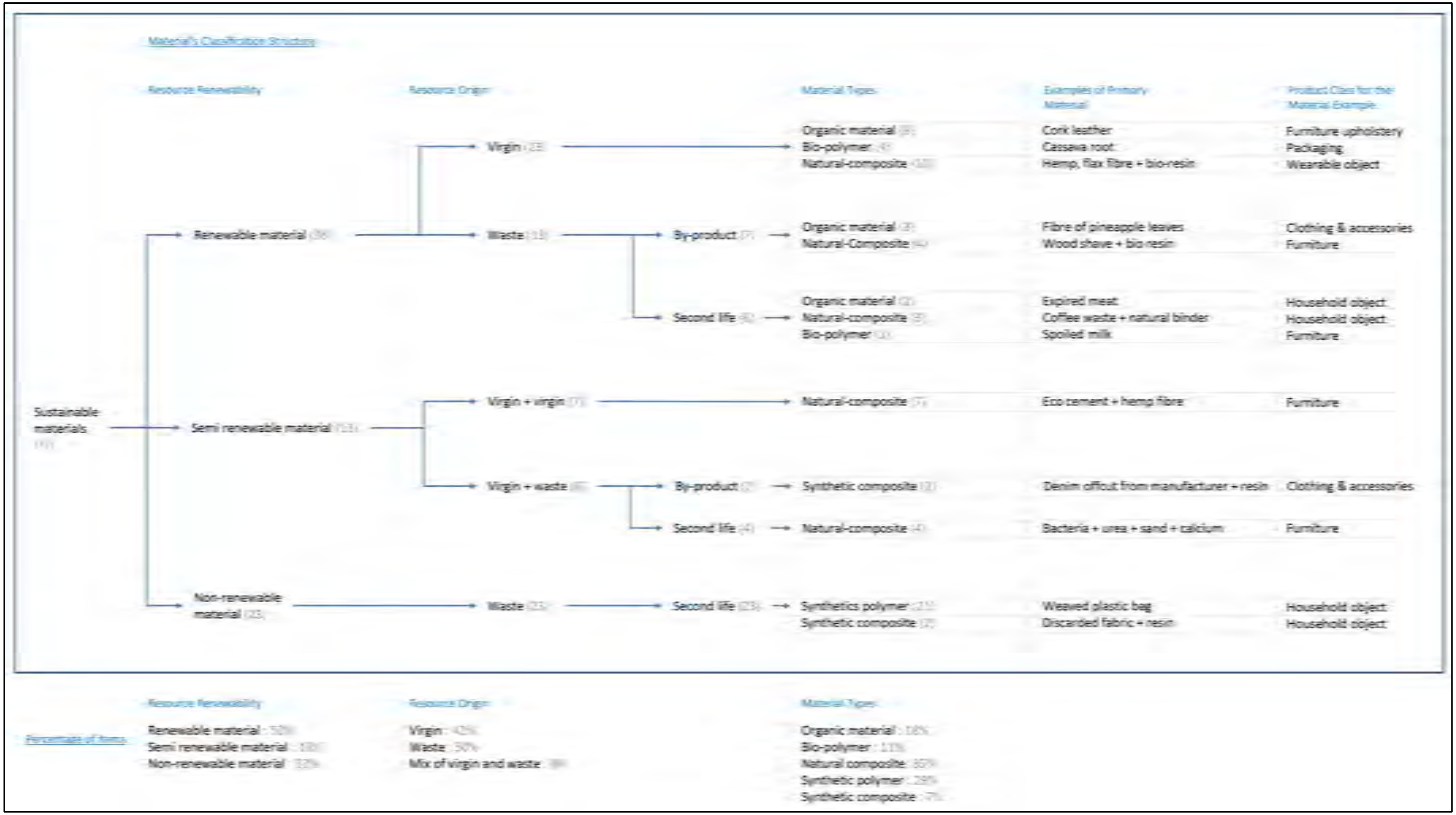

Figure 1. Classification of sustainable materials

Sustainable materials in practice

A closer examination of the seventy-two projects highlights the types of products made with the proposed materials. The types of products being developed are mainly furniture (37%), household objects (25%), clothing and accessories (18%) and packaging (11%). Figure 2 shows the breakdown of product types and Figure 3 examples of products in the dataset according to their materials types. Further analysis revealed which materials were used to make a particular product type, see Figure 4. The following trends were identified:

- Furniture was found to be increasingly made of natural composites and recycled plastics. The furniture products developed the most are seating items such as stools, chairs and benches. For example, a chair was made from a composite of wood fibre and fish oil, and an outdoor stool was made from discarded milk and detergent bottles. The reason for making seating furniture is that these products are simple creations that allow materials' technical properties (e.g. strength) to be easily tested and variation of surface qualities to be artistically embraced such as the concept of *wabi-sabi* (unique imperfection).
- Household objects were found to be predominantly made of recycled plastics and natural composites. Examples are bowls made from particles of recycled melamine, and a lamp cover made from coffee waste and a natural binder. Similar to furniture, household objects made from recycled plastics and natural composites are limited to simple products and the design indicates that basic moulding processes were adopted for production.
- Clothing and accessories were found to be made of recycled plastic and organic materials. Recovered PET and HDPE bottles were recycled into fabric and toothbrushes. In another case, waste plastics were reused to make bags adopting craft methods such as weaving. The utilisation of organic materials for clothing and accessories is still at the initial stages of material exploration. Although organic materials are still not fully developed for this application, attempts were made to convert them into products based on their technical properties (e.g. the flimsiness of bio-films is being associated with the softness of fabric thus the material is proposed to be used in making garment).

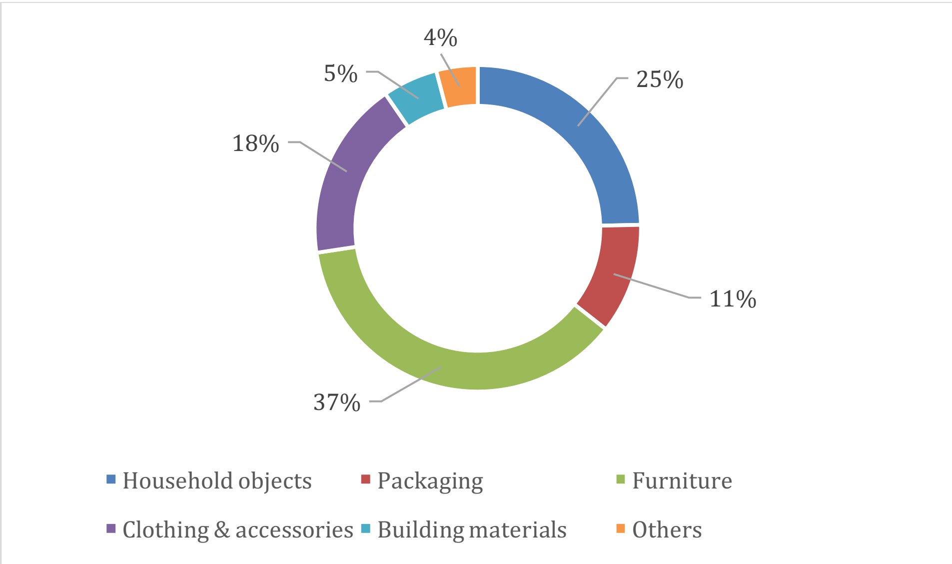

Figure 2. Product types

Figure 3. Sustainable materials and products

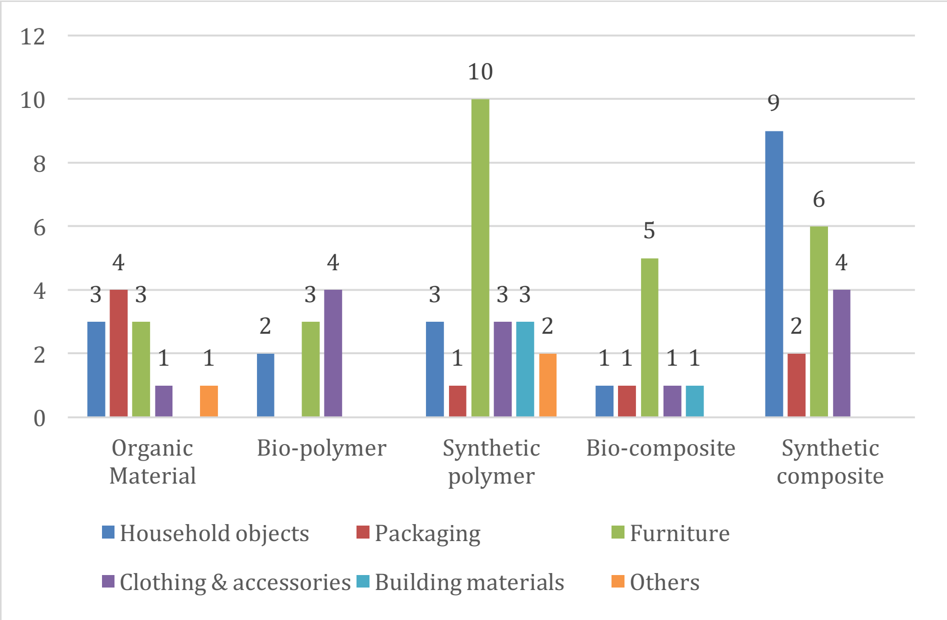

Figure 4. Sustainable materials and products application

Discussion

This research has shown that the majority of the materials were renewable and play a prominent role in balancing the depletion of non-renewable resources. They are predominantly based on virgin plant cellulose, agricultural by-products and food industry waste and the main outputs are natural fibre composites. The search for renewable materials is also focusing on the exploration of extraordinary living organism materials and uncommon waste materials. These materials portray the richness of the exploration undertaken within design communities. Although some materials are highly conceptual, it is noteworthy that a few extraordinary materials have progressed towards commercialisation. An example is a jacket made with bio-engineered bacteria by a well-known outdoor clothing company.

Non-renewable materials frequently originate from waste but waste also included various instances of renewable materials. Hence, the research has demonstrated that a culture for waste-reuse is progressively entering product design. The abundance and proximity of a waste resource provided a solid justification for its use. Interestingly, if a waste resource was collected from polluted environmental areas, e.g. the ocean, that resource was perceived as having an additional sustainability element which was often used to market the proposed product.

Due to its abundance, plastic waste is the most typical example of resource reuse or recycling. This is a way in which the destination to landfill of plastics is diverted back into the usage loop. Some recycled plastics were mixed with virgin bio-plastics; this is to attempt to improve the technical properties of the end material as well as to reduce the volume of plastic waste in the environment. This practice is expected to induce partial degradation of the inert material at the end of its life. With sufficient amount of biodegradable component in the mixture, the non-biodegradable component is expected to disintegrate and decay while the biodegradable component is consumed by microorganism (Wojtowicz, Janssen, & Moscicki, 2009). Other practices to induce synthetic polymer degradation include use of bacteria and fungi (Kim, 2003; Kyaw, Champakalakshmi, Sakharkar, Lim & Sakharkar, 2012; Sivan, Szanto & Pavlov, 2006).

The products studied vary significantly in terms of size, primary function and conventional materials that they are made from. Nevertheless, the products developed are limited to simple objects and only a case of material application in an electronic product is found. In general, various applications of sustainable materials were meant for material substitution and improved technical properties.

Interestingly, a significant number of unusual materials in the dataset were developed to support creative expression and provide new sensorial experiences to users. For example, the expired meat project which was exhibited at a design fair indeed provoke users' emotions during the interaction with the material.

In the Sustainable Materials Exploration section, we argued that terms such as environment-conscious materials, materials with high sustainable potential, and eco-sensitive materials are increasingly used to refer to materials with varying sustainable credentials. We also suggested that there is a need to consolidate current terminology used in the field. Departing from an analysis of materials used in practice, this research has shown important differences in sustainable materials and has proposed classes to characterise them. We have not looked at the thorough environmental footprint analysis of these materials. Renewable materials, for example, are often thought of as an ideal resource offering great potential for biodegradability. However, renewable virgin materials have to be grown, harvested and processed prior to usage. In contrast, waste materials exist in a ready-to-use state or semi-finished state. These facts do not necessarily have to favour waste materials since it is unrealistic to fully rely on them. Another intricate issue that has to be considered is the social impact of sustainable materials as in some contexts, the commercialisation of sustainable materials create jobs, help clean sluggish areas and revamp a material culture.

Limitations and further work

The research is based on seventy-two material centred design projects and on publicly available data about them. A larger data set of materials and richer data are necessary to develop a deeper understanding of the breath of sustainable materials. Future studies could expand the focus to understand the experience of users with these materials particularly those with peculiar surface characteristics and unusual origins as these aspects may possibly form the personality of the materials.

Conclusions

This research was undertaken with the aim to develop new understanding of sustainable materials developed within design projects. A dataset of seventy-two materials was collected and analysed using three categories, namely resource renewability, resource origin, and material group. Natural composites and recycled synthetic polymers are the materials predominantly used followed by organic materials. In order of frequency, the products produced with these materials are furniture, household objects and, clothing and accessories. Overall, this research has shown that the exploration of sustainable materials is vibrant and progressive but the market impact is still ambiguous. The development of sustainable materials was found to be at its infancy but undergoing a dynamic development. Proper strategies are needed to make these materials become commercial and design can play an important role in facilitating their uptake in the market.

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Sustainable materials in design projects

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Abstract

New types of sustainable materials are introduced in our markets every year to minimise the environmental impact of products. The search for more environmentally benign materials is crucial in reducing the depletion of non-renewable material resources. Recent literature indicates that there is a growing interest and rapid technological progression from various industry stakeholders on this matter. Nevertheless, the sustainability issues pursued by designers and other material developers are still ambiguous. The overall aim of this research is to develop new understanding of the sustainable materials being developed and applied in product design. Seventy-two material-centred design projects are analysed in terms of resource renewability and resource origin. The data obtained are further classified according to the material group and products produced with such materials. Renewable materials make up half of the materials used. Moreover, waste materials comprise up to half of the materials used. Three materials groups were found to be more frequently used, namely natural composites, synthetic polymers and organic materials. Most of these materials are being made into furniture, household objects and clothing and accessories. Within the natural composites and organic materials, various extraordinary materials were used, reflecting the dynamicity of designers' work and experimentation with materials. As for synthetic polymers, recycled plastics are the main materials used and this is not surprising given their abundance in the environment. In general, the application of sustainable materials seems to be at its infancy but explorations are vibrant and progressive. The impact of these materials in the mainstream market is unknown and other sustainability factors need further evaluation. As such, design as a discipline is yet to facilitate the uptake of these materials.

Keywords

Sustainable materials, sustainable design.

Every year millions of products are sent to landfills due to a throw-away culture. This rate of consumption will continue to grow, thus putting a strain on material resources and the environment (OECD, 2013). As a result, product developers have a growing interest in moving towards use of sustainable materials. Current initiatives to introduce sustainable materials are still in their early days with sustainability principles only starting to affect product development strategies. At a consumer level, while there is evidence that purchase decisions are influenced by companies' commitment to positive environmental impact, information made available to consumers on environmental friendly products remains limited and ambiguous (Brécard, 2014). For example, emphasis is placed on environmental and social attributes of products but the actual scientific proof of many claims is unknown (Hoek, Roling, & Holdsworth, 2013). Further to this, in a material context sustainability is dependent on many factors, which make any argument about the sustainability of materials complicated.

This research aims to characterise sustainable materials used in design projects and explore what products are being made with them. The results of this research reveal the breadth of materials developed and applied. The characterisation of materials proposed in this research is useful to improve the quality of the discussion on sustainable materials and particularly the sustainability argument made. Furthermore, this research helps identify distinct efforts to overcome the depletion of non-renewable materials and reflect on the emphasis and attention that these should be given.

Materials and sustainability

While global resources are further stressed by a push for faster consumption of short lifespan products (Rivera & Lallmahomed, 2015; Agrawal, Kavadias, & Toktay, 2015) and the rapid growth of developing countries (Fiksel, 2006) sustainability concerns remain in the fore. As Miller (1972) highlights, the critical boundary of resource consumption is beyond the shortage of reserve and includes the adverse impact on the environment. The sustainable use of resources (i.e. materials) then needs to be addressed if we are to realise the vision presented in the Brundtland Commission's report *Our Common Future*, in which current use does not adversely affect future generations (World Commission on Environment and Development, 1987).

The central theme of materials and sustainability is to minimise the adverse impact of materials to humans and the environment through well-planned management. However, even defining sustainability can be complicated since it is dependent on multiple stakeholders' views and contexts (Arroyo, Tommelein, & Ballard, 2016). For instance, the meaning materials convey changes with use and can lead to less favourable consumer appraisals or behaviours in terms of sustainability (Baxter, Aurisicchio, & Childs, 2015, 2016). It is also often too simplistic to regard certain materials as (un)sustainable as perfect data on the reserve of non-renewable materials is often difficult to obtain (Graedel et al., 2012). The result has been the development of several objectives and guidelines to move toward more sustainable use of materials. McDonough and Braungart (2002) have emphasised the need to manage material resources through efficient lifecycles including closed-loop processes in which waste is avoided. Ashby and Johnson (2010) have placed a time to this management suggesting that the timescale of sustainability concern should be fifty years into the future . Achieving these objectives is aided by the concepts of detoxification and dematerialization. Detoxification describes the attempt to reduce toxic materials used in material production or manufacturing processes, which includes the use of renewable resources for chemical substance (Weenen, 1995). Dematerialisation is concerned with the substitution of virgin materials with recycled materials, (Fiksel, 2006) and resource intensive materials with sustainably harvested and renewable materials (OECD, 2010) .

Assessment of sustainable materials is aided by several metric based tools that have emerged such as life cycle assessment and ecological footprinting (Robèrt, 2000). Typical considerations are environmental impact, resource efficiency, waste minimisation, life-cycle cost and performance capability. Some industries move beyond assessments to also place labels on products to try to communicate various types of sustainable solutions. For example, the textile industry features a host of eco-labels including: compostable, degradable, designed for disassembly, extended product life, energy recovery, pre or post-consumer materials, recycled materials, reduced energy, reduced water consumption and reduced use of resources (Targosz-Wrona, 2009).

Sustainable materials exploration

Designers are continuously tinkering to expand their knowledge and find new materials and manufacturing processes. In recent years, this activity includes the exploration of sustainable materials. This work is partly driven by the democratisation of knowledge and production technology (Rognoli, Bianchini, Maffei, & Karana, 2015; Mota, 2011) the output of which is an increasingly large category of 'DIY' materials (Rognoli et al., 2015). This is further facilitated through maker communities

(Thilmany, 2014). Importantly material research is not limited to self-exploration, as multidisciplinary knowledge sharing platforms (e.g. the open workshops on bio-materials held by the Co-Lab at the Institute of Making, University College London) are also contributing to the dissemination of materials knowledge to the public.

Within design, materials with sustainable credentials are variously referred to as environment-conscious materials (Utsugi, Yiyin, Abe, & Shiraishi, 2007), materials with high sustainable potential (Rognoli, Salvia, & Levi, 2011) and eco-sensitive materials (Karana & Nijkamp, 2014).The difference between these terms is not always clear but the breadth of these terms is not altogether surprising since the area of sustainable materials is growing and is still divergent in thinking. Consolidating current work in this area into a general term in order to better understand the types of materials considered sustainable is central to the aim of this work.

One prominent theme found in the literature is the utilisation of abundant waste materials in new forms. Examples of this include: discarded wet blue leather remainders in the huge leather industry in Brazil used to produce oven gloves (Júnior, Cândido, & Guanabara, 2008); clay soil from rural areas in Spain used to make unfired-bricks for the construction industry (Miqueleiz et al., 2012); and *xylan* and *mannan*, widely available from the side-streams of agriculture and forestry and used to make sustainable packaging products (Mikkonen & Tenkanen, 2012).

The use of unconventional materials with peculiar surface characteristics in which imperfection is embraced and considered an appealing aesthetic is another emergent theme. Examples of such projects are: Tomas Gabzdil Libertiny's bees hive vase (Parsons, 2009); Suzanne Lee's bacterial cellulose jacket; Gingers Krieg Dosier's microbial-induced bricks (Ginsberg, 2014); a tissue-cultured jacket (Catts & Zurr, 2014); and seeds' tablets and pots based on coffee waste, which were designed using a tool known as Material Driven Design (Karana, Barati, Rognoli, & Laan, 2015).

Another theme is the exploration of living materials, i.e. materials embodied in products which possess additional 'interactive' features. These materials are often called smart materials as they sense and respond to environmental stimuli in a predicted manner (Tao, 2001; Stamhuis, 2015). Living materials are unique since they benefit from how the 'living' features contribute to additional facets of sustainability. Examples include: the oxygen-breathing 'silk-leaf' by a Royal College of Art graduate (Melchiorri, 2014), responsive bacterial based 'bio-skin' fabric by MIT Media Lab (Biologic, 2015), and bacterial mineral precipitation 'self-healing' concrete by TU Delft (Jonkers, 2007). The future of everyday living with these interactive materials or products that mimic living organisms were speculated by Johanna Schmeer from the Royal College of Art in a project called Bio-plastic Fantastic (Schmeer, 2014).

Research methodology

The literature review provided useful insights on the vast spectrum of sustainable materials explored by designers. In order to fulfil the aim of characterising sustainable materials, material projects were analysed and classified. This section presents information about the dataset of materials collected during this research and explains how the data was analysed and classified.

Data collection

Seventy-two material-centred design projects were collected from various sources including design websites and design fairs. Projects were selected for consideration if they had: i) a focus on sustainability; ii) an objective to research and implement a sustainable material; and iii) a goal to output a consumer product. For each project, the following information was collected: material, end-product produced, and developer. Materials ranged from creative explorations to industry-led projects. Products included both semi-developed and commercial objects. Developers included academia, designers, start-up companies and established companies.

Category	Class	Definition	Example
Resource renewability	1. Renewable	Material made from natural organic resources.	Bio-plastic from corn starch, bacterial cellulose based material etc.
	2. Semi-renewable	Material made from two or more constituent materials of which at least one is renewable.	Wood wool and cement composite, bio-plastic reinforced fiberglass composite, etc.
	3. Non-renewable	Material made from a finite natural resource.	Synthetic polymer from petroleum, etc.
Resource origin	1. Virgin	Material made from a resource that has not been previously used or consumed.	Bamboo, wood plank, etc.
	2. Waste: by-product	Material made from waste that is a left-over of a production process.	Pineapple leave fibre-based material, agriculture residue, etc.
	3. Waste: second life	Material made from waste that is obtained from a product which has reached its end of life.	Expired meat, spoiled milk etc.
Material group	1. Organic	Material derived from biological substances.	Wood, cotton, bio-film, etc.
	2. Bio-polymer	Polymer-based material derived from biological substances.	Bio-plastic from plant cellulose, bio-plastic from corn starch, etc.
	3. Synthetic polymer	Man-made polymer from artificial components.	Polyethylene terephthalate (PET), high density polyethylene (HDPE), etc.
	4. Natural composite	Material formed by the combination of natural or synthetic reinforcement and natural matrix.	Natural fibre reinforced bio-polymer, e.g. composite of hemp fibre and bio-resin; natural fibre reinforced organic material, e.g. composite of wood and mushroom; natural fibre reinforced inorganic material, e.g. composite of natural fibre and clay; synthetic fibre reinforced bio-polymer, e.g. carbon fibre reinforced bioplastic.
	5. Synthetic composite	Material formed by the combination of natural reinforcement and synthetic matrix.	Natural fibre reinforced synthetic polymer, e.g. composite of cotton yarn and resin.

Table 1. Sustainable material categories

Results

The materials in the data set were classified into three categories, namely resource renewability, resource origin and material group, see Table 1. The resource renewability category distinguishes if a material is from a renewable, non-renewable or semi-renewable source. The resource origin category characterises if a material is from a virgin or waste resource. The material group category classifies materials in five types, namely organic, bio-polymer, synthetic polymer, natural composite, and synthetic composite. This category, initially informed by the work of (Ljungberg & Edwards, 2003), has evolved following a data-driven approach, in which data was analysed to identify patterns and classes have emerged based on the data interpretation. The two composite material classes deserve a special note to explain how materials have been assigned to them. In a composite the matrix material surrounds and supports the reinforcement material by maintaining their relative positions. Typically, the matrix material is significantly higher in volumetric percentage than the reinforcement material, and therefore it affects more its sustainability. On this basis the distinction between a natural composite and a synthetic composite was made depending on whether the matrix is from a natural or synthetic material.

The products were also classified into categories including: furniture, household object, clothing and accessories, packaging, building material, and others, see Table 2.

Household objects	Packaging	Furniture	Clothing & accessories	Building Materials	Others
Plate, mug, bowl, pot, clock, toothbrush, vase, basket, mat, toys, hoover.	Bottle, plastic bag, void fill packaging, fruit-carrier bag, razor packaging.	Stool, chair, bench, lighting, side table, table, outdoor seating.	Dress, shoes, textile, dress, necklace, sneaker, bag, sunglass.	Acoustic panel, bricks, tiles, flooring.	Musical instrument, car interior finish, surfboard, 3D printer filament.

Table 2. Product categories

Sustainable materials classified

The materials used in the data set were mapped according to the previously introduced categories, see tree in Figure 1. The numbers in brackets along the branches of the tree represent the frequency of the materials in the dataset in term of actual instances. At the bottom of the tree, material percentages for the classes of each category are provided.

The classification includes three main branches, which follow the classes of the resource renewability category. Results show that 50% of the materials are renewable, 18% semi-renewable and 32% non-renewable, see Figure 1. The classification further splits materials into sub-branches dependent on the resource origin category. This shows that 42% of the materials are virgin, 50% waste, and 8% a mix of virgin and waste. Waste can be a by-product of a consumption process, or a material which can have a second life. Finally, the classification identifies five material groups (see Figure 1) the largest of which are: natural composites (35%), synthetic polymers (29%) and lastly organic materials (18%).

The first branch of the classification is 'renewable materials'. Within this*, virgin* materials lead to organic materials (9), bio-polymers (4) and natural composites (10). An example of an organic material is cork leather. Examples of bio-polymer and natural composite are plastic from corn-starch and a natural fiber composite from hemp, respectively. *By-products waste* materials lead to organic materials (3) and natural composites (4). Fibre from pineapple leaves is an example of organic material, whereas a composite of wood shave and a bio-resin is an example of a natural composite. *Second life waste* materials consist of organic materials (2), natural composites (3), and bio-polymers (1). Examples of these are expired meat, a composite of coffee waste and a natural binder, and plastic from spoiled milk, respectively.

The second branch is 'semi-renewable materials'. Within this branch, *virgin-virgin composite* materials lead to natural composites (7). An example is a composite of eco-cement and hemp fibre. *Virgin-waste composite* materials are further split into materials with a *by-product waste* and *second life* *waste*. *Virgin-by product waste* materials lead to synthetic composites (2). An example is denim offcut from manufacture and resin. *Virgin-second life waste* materials consist of natural composites (4) and an example is a composite of bacteria, urea, sand and calcium.

The third and last branch is ‘non-renewable materials. Within this branch, *second life waste* materials lead to synthetic polymers (21) and synthetic composites (2). An example of the first material type is weaved seatbelt and discarded fabric and resin is an example of the second material type.

The five material groups, namely organic materials, bio-polymers, synthetic polymers, natural composites and synthetic composites, are now examined.

<u>Organic materials</u>: this group includes virgin materials from plants and extraordinary examples of utilised waste including second life materials such as expired meat and by-product materials such as salmon skin and pineapple leaves. Some of these materials have an established process to convert them into products (e.g. salmon skin leather, bamboo), whereas others are still at conceptual level and require further research before the materials can be considered fully developed and feasible for commercial production (e.g. mycelium mushroom fabric, beetle’s chitin film).

<u>Bio-polymers</u>: this group includes plastics from virgin renewable resources such as corn starch. Some of these materials are already in the mainstream market, were sourced from companies with high-tech production technology and used as surrogate materials. The complexity of polymeric materials and the constraints of manufacturing facilities seem to hinder designers’ exploration thus making these materials among the least used. Still, there are early attempts to develop new bio-polymers from second life waste materials such as spoiled milk.

<u>Synthetic polymers</u>: recycled plastics make up the largest share of this group. This is expected since plastic waste from consumer goods is often abundantly available. Some of the plastics were reused, whereas others were recycled, i.e. they were broken down into their raw state and reprocessed into new products. The former type requires that technical properties such as rigidity are utilisable. As for recycled plastics, the production process requires uncomplicated procedures, compatible with existing plastic production methods thus providing ample opportunity for self-explored small scale production. For instance, high-density polyethylene (HDPE) bottle were converted into new products with self-made extrusion and injection moulding.

<u>Natural composites</u>: waste is the dominant origin of the resources used in this group. Among natural composites, there are predominantly natural fibre reinforced bio-polymers. However, natural composites were found to also include natural fibre reinforced organic materials, natural fibre reinforced inorganic materials, and synthetic fibre reinforced bio-polymers. The reason for this variety of composites is the ease of production of these materials. As such, many unusual materials were utilised within this material group, e.g. seaweed, algae, urea, manure etc. Several applications tend towards creative expression in which the combined materials were explored for new aesthetics as much as improved utility.

<u>Synthetic composite</u>: materials in this group are predominantly by-product waste and second life waste materials. In terms of production, these materials require simple procedures similar to the aforementioned natural composites. They are mostly post-industrial and post-consumption products that were combined with industrial resin. These materials are the least used in the dataset indicating that a bio-based matrix is typically the preferred option. Several applications portray the reinforcement materials in their original and unprocessed state, creating unique surface properties.

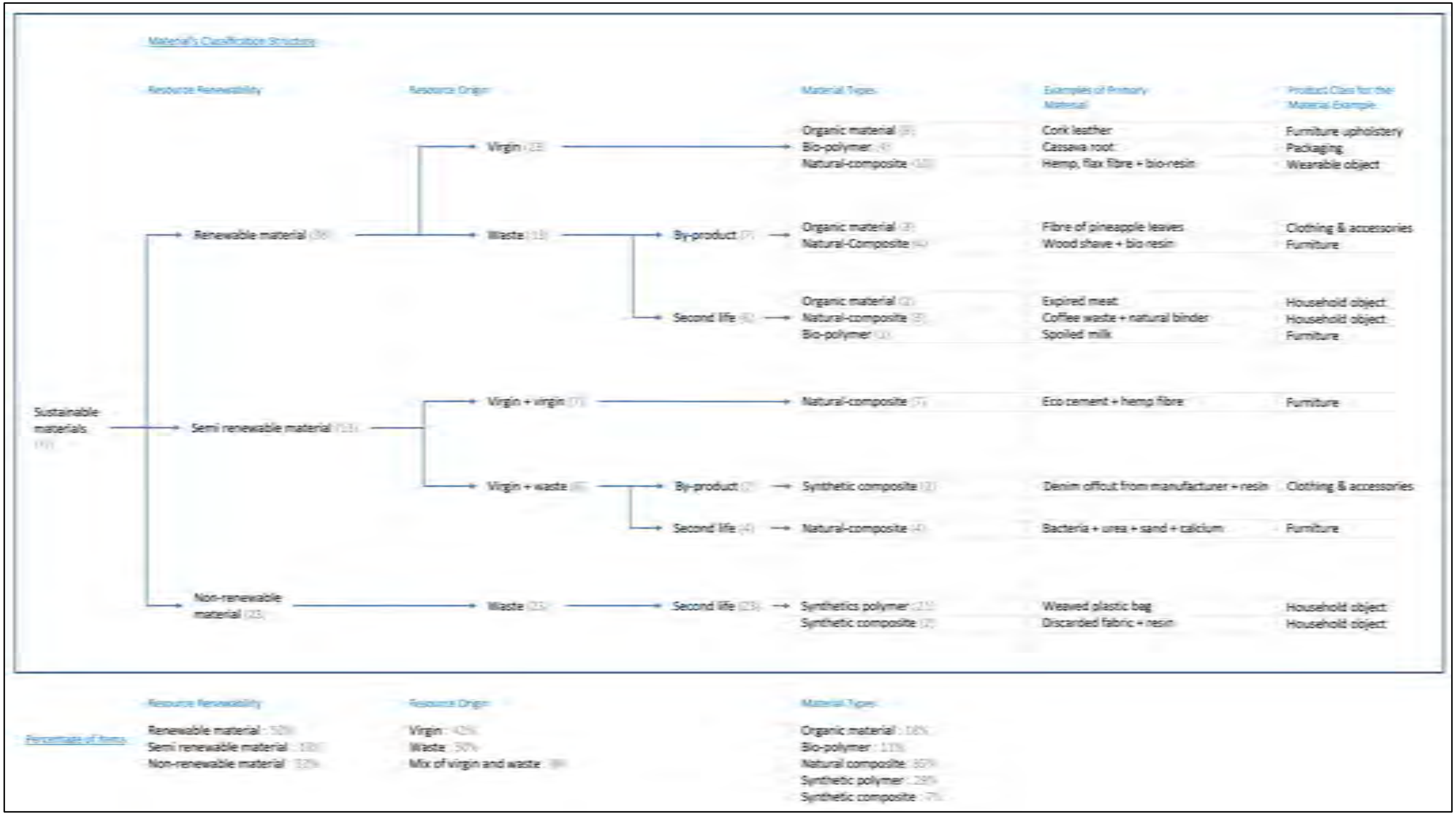

Figure 1. Classification of sustainable materials

Sustainable materials in practice

A closer examination of the seventy-two projects highlights the types of products made with the proposed materials. The types of products being developed are mainly furniture (37%), household objects (25%), clothing and accessories (18%) and packaging (11%). Figure 2 shows the breakdown of product types and Figure 3 examples of products in the dataset according to their materials types. Further analysis revealed which materials were used to make a particular product type, see Figure 4. The following trends were identified:

- Furniture was found to be increasingly made of natural composites and recycled plastics. The furniture products developed the most are seating items such as stools, chairs and benches. For example, a chair was made from a composite of wood fibre and fish oil, and an outdoor stool was made from discarded milk and detergent bottles. The reason for making seating furniture is that these products are simple creations that allow materials' technical properties (e.g. strength) to be easily tested and variation of surface qualities to be artistically embraced such as the concept of *wabi-sabi* (unique imperfection).
- Household objects were found to be predominantly made of recycled plastics and natural composites. Examples are bowls made from particles of recycled melamine, and a lamp cover made from coffee waste and a natural binder. Similar to furniture, household objects made from recycled plastics and natural composites are limited to simple products and the design indicates that basic moulding processes were adopted for production.
- Clothing and accessories were found to be made of recycled plastic and organic materials. Recovered PET and HDPE bottles were recycled into fabric and toothbrushes. In another case, waste plastics were reused to make bags adopting craft methods such as weaving. The utilisation of organic materials for clothing and accessories is still at the initial stages of material exploration. Although organic materials are still not fully developed for this application, attempts were made to convert them into products based on their technical properties (e.g. the flimsiness of bio-films is being associated with the softness of fabric thus the material is proposed to be used in making garment).

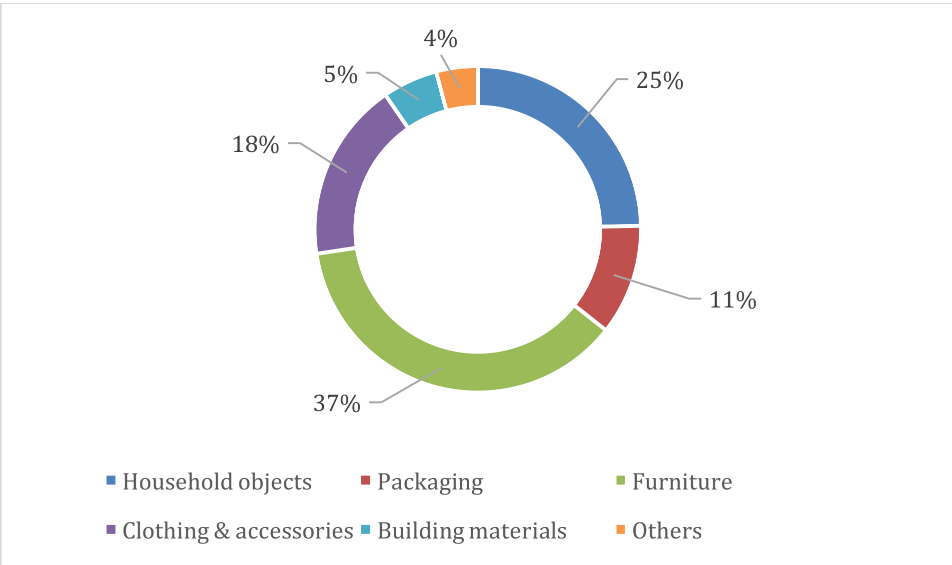

Figure 2. Product types

Figure 3. Sustainable materials and products

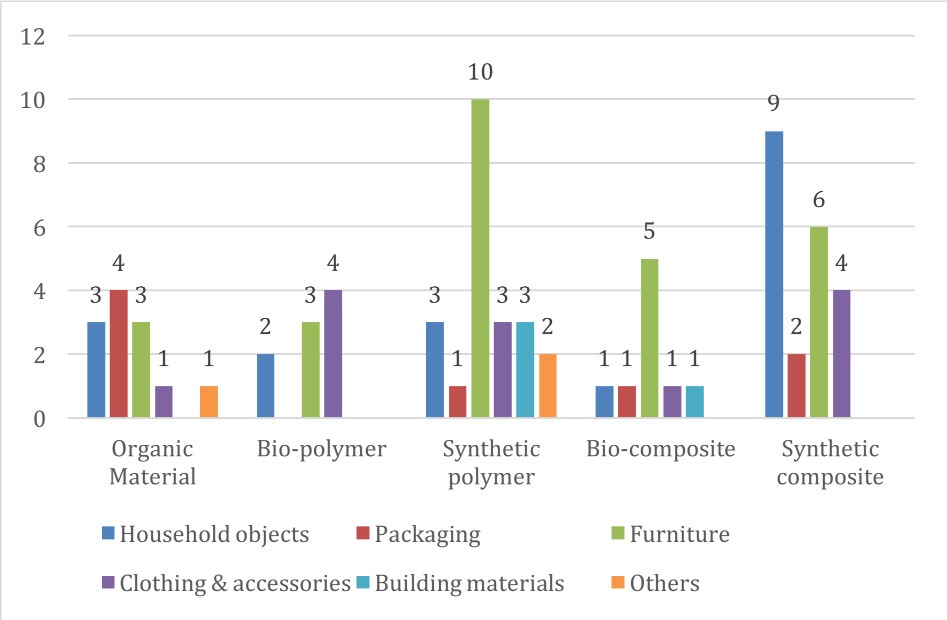

Figure 4. Sustainable materials and products application

Discussion

This research has shown that the majority of the materials were renewable and play a prominent role in balancing the depletion of non-renewable resources. They are predominantly based on virgin plant cellulose, agricultural by-products and food industry waste and the main outputs are natural fibre composites. The search for renewable materials is also focusing on the exploration of extraordinary living organism materials and uncommon waste materials. These materials portray the richness of the exploration undertaken within design communities. Although some materials are highly conceptual, it is noteworthy that a few extraordinary materials have progressed towards commercialisation. An example is a jacket made with bio-engineered bacteria by a well-known outdoor clothing company.

Non-renewable materials frequently originate from waste but waste also included various instances of renewable materials. Hence, the research has demonstrated that a culture for waste-reuse is progressively entering product design. The abundance and proximity of a waste resource provided a solid justification for its use. Interestingly, if a waste resource was collected from polluted environmental areas, e.g. the ocean, that resource was perceived as having an additional sustainability element which was often used to market the proposed product.

Due to its abundance, plastic waste is the most typical example of resource reuse or recycling. This is a way in which the destination to landfill of plastics is diverted back into the usage loop. Some recycled plastics were mixed with virgin bio-plastics; this is to attempt to improve the technical properties of the end material as well as to reduce the volume of plastic waste in the environment. This practice is expected to induce partial degradation of the inert material at the end of its life. With sufficient amount of biodegradable component in the mixture, the non-biodegradable component is expected to disintegrate and decay while the biodegradable component is consumed by microorganism (Wojtowicz, Janssen, & Moscicki, 2009). Other practices to induce synthetic polymer degradation include use of bacteria and fungi (Kim, 2003; Kyaw, Champakalakshmi, Sakharkar, Lim & Sakharkar, 2012; Sivan, Szanto & Pavlov, 2006).

The products studied vary significantly in terms of size, primary function and conventional materials that they are made from. Nevertheless, the products developed are limited to simple objects and only a case of material application in an electronic product is found. In general, various applications of sustainable materials were meant for material substitution and improved technical properties.

Interestingly, a significant number of unusual materials in the dataset were developed to support creative expression and provide new sensorial experiences to users. For example, the expired meat project which was exhibited at a design fair indeed provoke users' emotions during the interaction with the material.

In the Sustainable Materials Exploration section, we argued that terms such as environment-conscious materials, materials with high sustainable potential, and eco-sensitive materials are increasingly used to refer to materials with varying sustainable credentials. We also suggested that there is a need to consolidate current terminology used in the field. Departing from an analysis of materials used in practice, this research has shown important differences in sustainable materials and has proposed classes to characterise them. We have not looked at the thorough environmental footprint analysis of these materials. Renewable materials, for example, are often thought of as an ideal resource offering great potential for biodegradability. However, renewable virgin materials have to be grown, harvested and processed prior to usage. In contrast, waste materials exist in a ready-to-use state or semi-finished state. These facts do not necessarily have to favour waste materials since it is unrealistic to fully rely on them. Another intricate issue that has to be considered is the social impact of sustainable materials as in some contexts, the commercialisation of sustainable materials create jobs, help clean sluggish areas and revamp a material culture.

Limitations and further work

The research is based on seventy-two material centred design projects and on publicly available data about them. A larger data set of materials and richer data are necessary to develop a deeper understanding of the breath of sustainable materials. Future studies could expand the focus to understand the experience of users with these materials particularly those with peculiar surface characteristics and unusual origins as these aspects may possibly form the personality of the materials.

Conclusions

This research was undertaken with the aim to develop new understanding of sustainable materials developed within design projects. A dataset of seventy-two materials was collected and analysed using three categories, namely resource renewability, resource origin, and material group. Natural composites and recycled synthetic polymers are the materials predominantly used followed by organic materials. In order of frequency, the products produced with these materials are furniture, household objects and, clothing and accessories. Overall, this research has shown that the exploration of sustainable materials is vibrant and progressive but the market impact is still ambiguous. The development of sustainable materials was found to be at its infancy but undergoing a dynamic development. Proper strategies are needed to make these materials become commercial and design can play an important role in facilitating their uptake in the market.

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Five Kingdoms of DIY-Materials for Design

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Keywords
DIY-Materials;
Materials Experience;
Tinkering with Materials;
DIY-Materials Kingdoms.

Abstract
The DIY movement is expanding beyond products to the materials which embody products; namely, DIY-Materials. DIY-Materials are created through individual or collective self-production practices, often by techniques and processes of the designer's invention. In this paper, we elaborate on the sources that can serve as a departure point for DIY material practices. Analyzing above 150 design cases, we introduce five main categories of DIY-Materials based on the material sources. Inspired by the biological classification of elements of earth, we name these categories as DIY-Materials Kingdoms. We present each kingdom with example cases supported by rich visuals to illustrate the process and the outcome of the DIY-Materials design effort.

Introduction
The Do-It-Yourself movement expands beyond products to the materials that embody the products (Brownell, 2015). DIY-Materials in comparison to the industrial ones are "created through individual or collective self-production practices, often by techniques and processes of the designer's invention. They can be entirely new materials, modified, or further developed versions of existing materials" (Rognoli et al., 2015 p. 693). DIY material practices are characterized by the renaissance of craftsmanship (Bardzell et al., 2012; Bean & Rosner, 2012; Bettiol & Micelli, 2014; Sennett, 2008). They are also boosted by the democratization of technologies (Tanenbaum et al., 2013), and the practices, combining making, crafting and personal fabrication (Gershenfeld, 2005; Kuznetsov & Paulos, 2010). In fact, DIY practices ground on knowing in action (Schön, 1983), i.e. experiential knowledge obtained through making materials. The outcome of this process is often a self-produced material by thinking through the material at hand (Nimkulrat, 2012). Thus,


Linnaeus

CAROLI LINNÆI
Naturæ Curiosorum Dioscoridis Secundi
SYSTEMA NATURÆ
IN QUO
NATURÆ REGNA TRIA,
SECUNDUM
CLASSES, ORDINES, GENERA, SPECIES,
SYSTEMATICE PROPONUNTUR.

Editio Secunda, Auctior.

STOCKHOLMIÆ
Apud GOTTFR. KIESEWETTER.
1740.

REGNUM ANIMALE
Constat VI. Classibus.
I. QUADRUPEDIA. DJUR. Corpus pilosum. Pedes quatuor. Feminæ viviparæ, lactiferæ.
II. AVES. FOGLAR. Corpus plumosum. Pedes duo; Alæ duæ. Rostrum osseum. Feminæ oviparæ.
III. AMPHIBIA. KRAK. Corpus nudum vel squamosum. Dentes molares nulli, reliqui acuti. Pinnæ nullæ radiatæ.
IV. PISCES. FISKAR. Corpus nudum vel squamosum. Pedes nulli. Pinnæ semper.
V. INSECTA. MASKAR. Corpus ossibus cutis loco tectum. Caput Antennis instructum.
VI. VERMES. SKRIDFAR. Corporis musculi ab una parte basi cuidam solidæ affixi.
E CLAS-

INSECTA COLEOPTERA.
CLASSIS V.
INSECTA.
Ordo I.
COLEOPTERA. Elytra bina.
132. SCARABÆUS. Antennæ clavatæ, fissiles.
133. DERMESTES. Antennæ clavatæ, perfoliatæ.
134. COCCINELLA. Antennæ clavatæ. Corpus hemisphæricum.
135. CHRYSOMELA. Antennæ simplices, obtusæ, breves. Corpus subrotundum.
136. CASSIDA. Clypeus planus, marginatus, caput tegens.
137. CURCULIO. Antennæ clavatæ, insidentes Rostro cylindraceo, elongato.
138. NECYDALIS. Antennæ clavatæ. Clypeus angustus, teretiusculus.
139. GYRINUS. Pedes postici saltatorii.
140. LEPTURA. Pedes postici maximi. Clypeus subcylindraceus: Corpus tenue, acuminatum.
141. ATTELABUS. Antennæ articulis lentiformibus: ultimo elabato.
142.

Figure 1. Original Linnaeus taxonomy publication from 1758 with categories and sub-categories of Kingdom Animale - Source: Google.

the process of making materials by hand can be identified as a way of thinking intellectually (Sennett, 2008, pp. 149-153). In other words, in a DIY practice a dynamic process of learning and understanding through the experience of materials is required (Gray & Burnett, 2009, p. 51; Karana et al., 2015).

As explained by Ashby and Johnson (2002), “classification is the first step in bringing order into any scientific endeavor. The founders of biology, zoology, and geology were those who created the classification systems. Classification segregates an initially disordered population into groups that in some way have significant similarities”. Based on the previous statement from the field of materials for design, and assuming that historically science classifies materials, we started to look at the different sources that compose the DIY-Materials as a distinctive feature to provide a classification to what we consider to be a new class of materials.

In this paper, we present some of the best practices of DIY-Materials and classify them by asking ourselves: what can serve as a material source for a DIY-Material?

The cases we collected demonstrate that although they vary in outcome and activities, they are inspired by some common material sources. We argue that categorizing these cases will provide future designers who are interested in developing their materials for design purposes, with a departure point.

Delft University of Technology, The Netherlands

DIY-Materials classification: The Five Kingdoms

By analyzing the best practices of DIY-Materials found in all different sources of media available, we noticed how important was for designers to highlight the sources used for their projects as starting material. If for the traditional materials, it is a certainty that plastic comes from petroleum and glass comes from silica, the origins of DIY-Materials are not so evident. We started to create groups of similar items. Since the classification of objects means to combine them into categories based on common elements, we focused on a possible categorization for the DIY-Materials. We took inspiration by the first biological classifications of the XVII century (e.g. the work of the Swedish botanist, zoologist and physician Carolus Linnaeus called Systema Naturae (Linnaeus, 1758). Linnaeus published what became for many years the standard biological classification of elements of earth, known as the Linnaean taxonomy (figure 1). This landmark publication established a hierarchical classification of the natural world, dividing it into three main kingdoms: plant, animal and mineral. We acknowledge the modern biological nomenclature has evolved into several deeper divisions of nature's taxonomy (Copeland, 1938; Whittaker, 1969; Woese et al., 1977; Cavalier-Smith, 1998; Ruggiero et al., 2015).

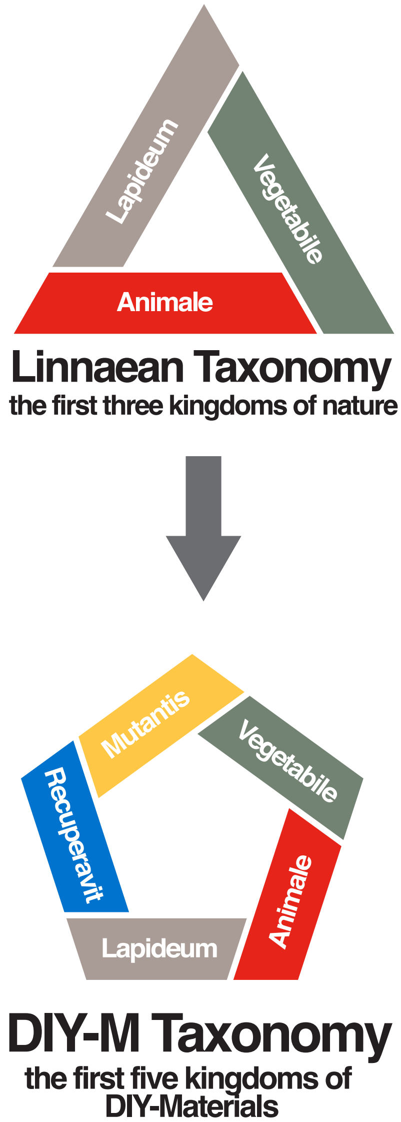

Figure 2. Adaptation of taxonomy for DIY-Materials

Similar to Linnaean taxonomy, the DIY-Materials classification ground mainly on the sources of the material and their origins. We individuated five groups, and we called them kingdoms. (figure 2. The evolution of the Linnean taxonomy into the DIY-Materials classification; figure 3. the five DIY-Materials kingdoms and their icons). We analyzed above 150 cases; we present 50 of these cases in this paper due to page number limitations (figure 4).
We define the five DIY-Materials kingdoms as follows:

(1) Kingdom Vegetabile:
When the primary source for a DIY-Material derives from plants and fungi, we categorize the material under the Kingdom Vegetabile. In this case, we have maintained the original Linnaean taxonomy where "fungi" belong to the XXIV Class Cryptogamia. Materials under this kingdom differ from the others, particularly because they can derive from growing or farming techniques. Designers who create materials under this category collaborate with, for example, farmers and biologists (figures 5, 6).

(2) Kingdom Animale:
refers to all material sources derived from animals and bacteria. Note that bacteria were unknown when the Linnaean taxonomy appeared, but due to its behavior as a living organism, we inserted it into this kingdom. Those materials can be developed either by collaborating with living organisms or by using parts of the animals, like hair or bones (figures 7, 8).

(3) Kingdom Lapideum:
it contains all DIY-Materials, which come from minerals: stones, sand, ceramics, clay, etc. Some current cases combine sources from other kingdoms, such as wool or cotton fabrics, but in a lower percentage compared with the main constituent. Another feature in this kingdom is its strong link to crafts, probably because these types of materials have a long tradition in our material culture (figures 9, 10).

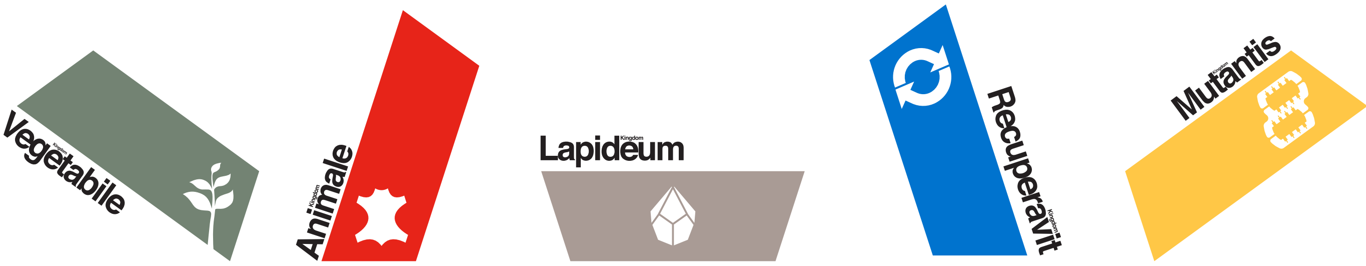

Figure 3. The five kingdoms symbols to classify DIY-Materials.

(4) Kingdom Recuperavit:
comprise all sources society consider as waste but have the possibility to transform into a valuable resource. They often come from plastic, metal or organic waste, sometimes as side products of industrial production. It is at the moment the biggest kingdom by the number of cases observed. Inside this kingdom, it is clearly visible the designer`s intention towards a more conscious and sustainable future. (figures 11, 12).

(5) Kingdom Mutantis:
includes the DIY-Materials created from different technological mixes and hybridization of industrial, interactive or smart (Ritter, 2007) sources. We included in this category, combinations of different material sources that come from another kingdom but evolve into something particular with the aid of any technology. According to the field of biology, mutations play a role in both normal and abnormal biological processes of life including evolution. We refer to all cases where a transformation occurs with the aid of technology. This transformation represents a significant change in the material's nature and behavior in comparison to other kingdoms (figures 13, 14).

In the following pages, we present a description of selected best practices that represent each kingdom.

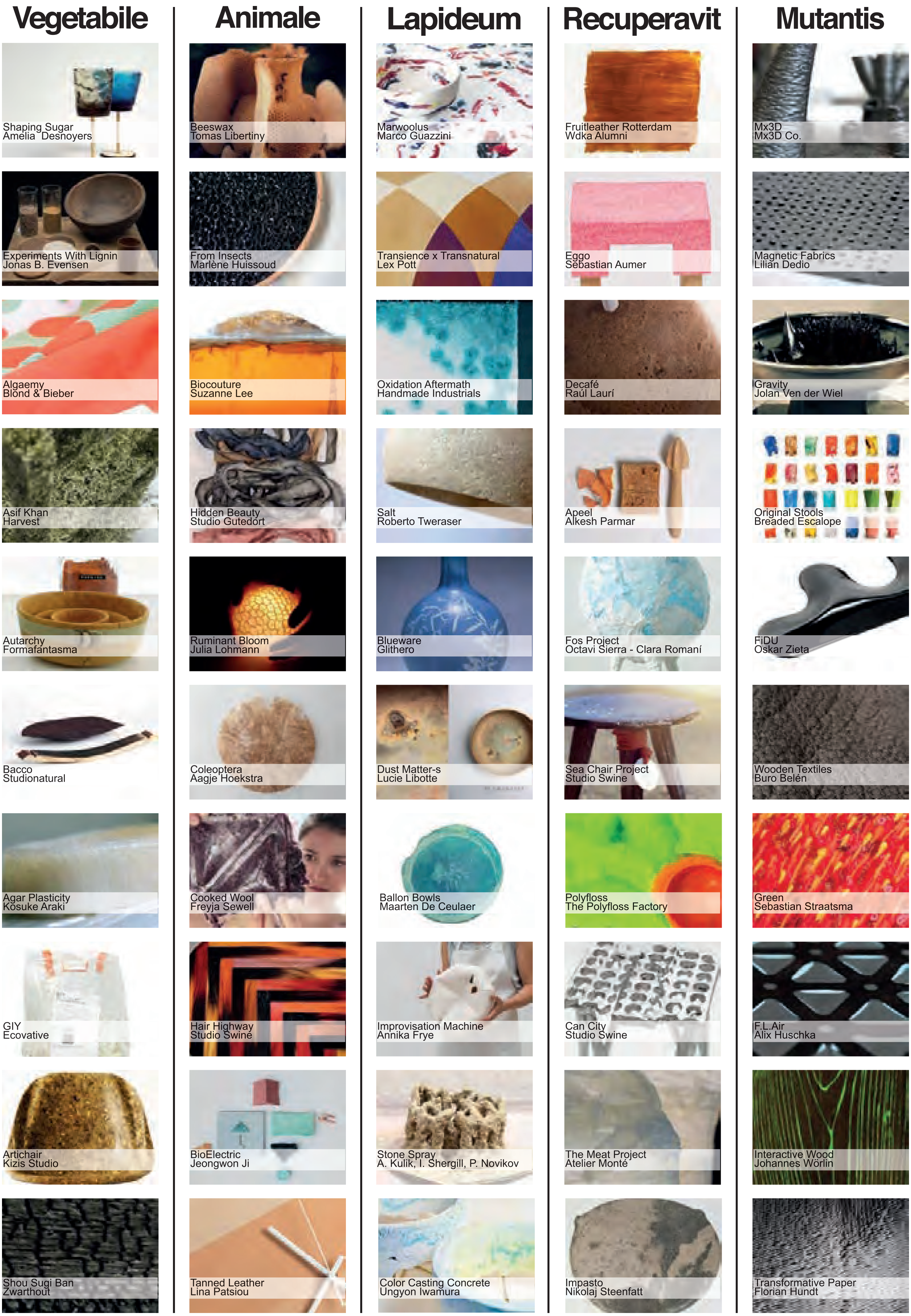

Figure 4. Selected cases from the five kingdoms of DIY-Materials.

Autarchy
Kingdom Vegetabile
Is a project from the studio Formafantasma based in the Netherlands. Here the designers in collaboration with a Baker have developed a natural material composed of flour, agricultural excess, and natural limestone. The color palette of the different samples comes from vegetables, spices and some roots that provide their natural dyes. The designers presented the project as an installation, which aims to express the statement of the possibility to elaborate products without producing any waste. Autarchy also suggests that it is possible to create objects with the aid of inherited knowledge from other disciplines, where by doing so, a designer can find sustainable and uncomplicated solutions.

Figure 5. Autarchy - Kingdom Vegetabile.

Agar Plasticity
Kingdom Vegetabile
Is an ongoing development by the Japanese AMAM Studio led by designer Kosuke Araki. Material developed from seaweed with a mix of agar, a substance obtained by boiling red algae, takes inspiration from the Japanese tradition to make sweets. Is obtained in powder, sheets and block formats with different thickness and hardness that allows creating any desired shape. With the intention to replace different plastic-made products, the designer states that the plasticity of agar can be taken further with the aid of other disciplines.

Figure 6. Agar Plasticity - Kingdom Vegetabile.

Hidden Beauty

Kingdom Animale

Studio Gutedort in Germany has produced a collection of objects by using a common yet strange material to people. Bowels and bladders from animals have been tanned for centuries creating a paper-like material yet more resistant. With the arrival of new industrial materials that could better perform in several applications, the natural material disappeared from common uses almost two centuries ago. In search of new aesthetics, the designers appeal to the idea of transforming those disused materials into honest and unique source for products that can reveal their hidden value. By achieving a more leather-like appearance, the studio pretends to celebrate the material properties without denying its origins.

Figure 7. Hidden Beauty - Kingdom Animale.

Coleoptera

Kingdom Animale

This is a project undertaken by the designer Aagje Hoekstra. The material is made out of pressed insect shells. Mealworm beetle is a particular insect commonly used as bred for the animal food industries in their larvae state. Once is dead after completing its natural life cycle, the shell is left without any other use. The shell itself contains Chitin which is a very common natural polymer, that is furthermore pressed with the remaining parts of the animal to obtain a fascinating material with particular sensorial qualities like semi-transparency and texture.

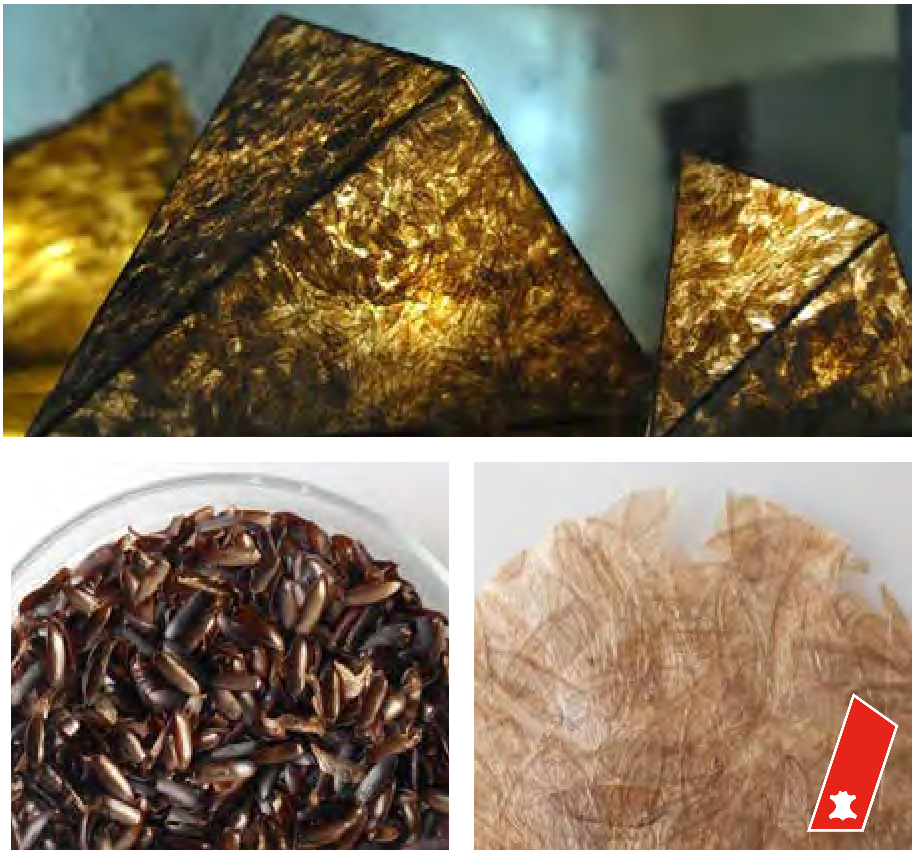

Figure 8. Coleoptera - Kingdom Animale.

Marwoolus
Kingdom Lapideum
This is a material developed by Marco Guazzini where two opposite sources meet: marble and wool. The uncommon mix derives from the cultural connections of the designer with the places where both materials are extracted and processed. The result is a colorful piece of marble with unique expressive-sensorial qualities (Rognoli, 2014).

Figure 9. Marwoolus - Kingdom Lapideum.

Balloon Bowls
Kingdom Lapideum
Developed by Maarten De Ceulaer, the project defeats traditional industrial molding processes. By inserting a type of clay with a polymeric hardener in the middle of two air-inflated balloons, the designer can create unique shapes that could be difficult to obtain with industrial tools. Every piece becomes unique as the behavior of the balloon molds is difficult to standardize. The results regarding shape and visual texture are distinct to each other.

Figure 10. Balloon Bowls - Kingdom Lapideum.

Sea Chair Project
Kingdom Recuperavit
Studio SWINE decided to embark on a quest for the different plastic waste particles that floats on the surface of the sea. Once the plastic material is collected, a standard piece of furniture is created with the aid of DIY tools. Although the shape of the object may not be aesthetically pleasant, it is interesting that a tag with the coordinates where the plastic pieces were collected adorns it. By doing that the designer transforms a waste material into something valuable.

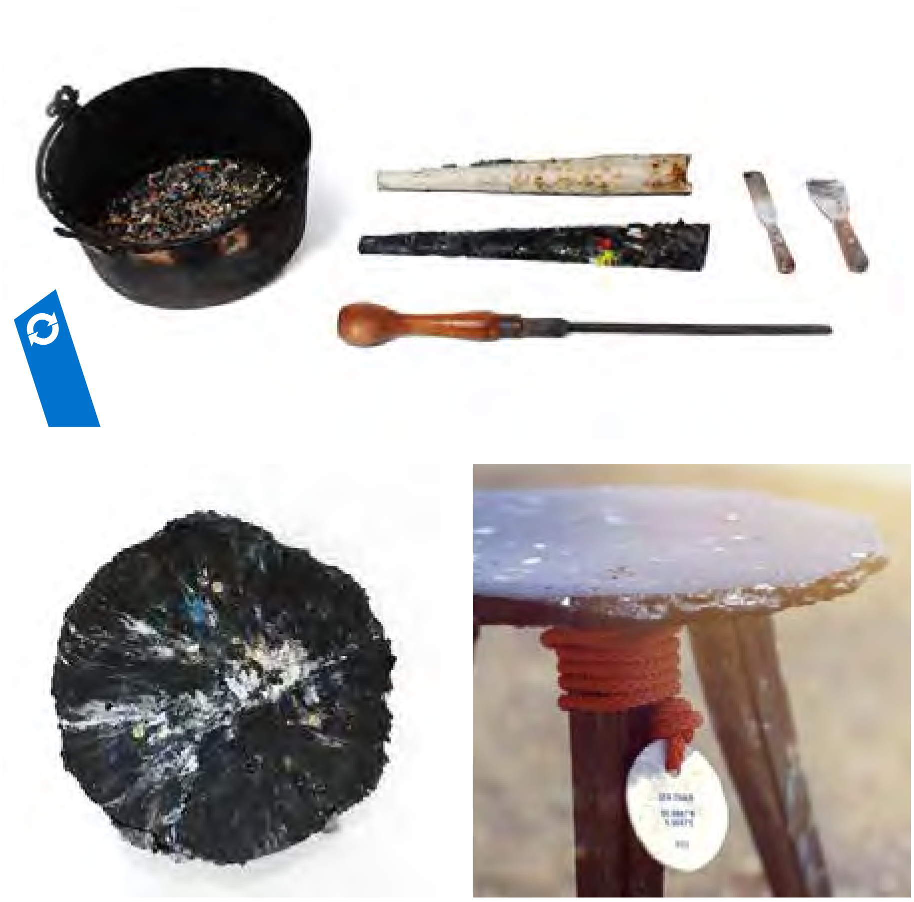

Figure 11. Sea Chair Project - Kingdom Recuperavit.

Decafé
Kingdom Recuperavit
It is an ongoing project by Raúl Laurí. Like many similar projects, the primary concern derives from the excessive amount of food waste produced by humans. Coffee delivers every day millions of tons of waste. The designer`s intention is to convert coffee waste into a material with a particular sense of aesthetics that can be used to create different products.

Figure12. Decafé - Kingdom Recuperavit.

MX3D
Kingdom Mutantis
Developed by Joris Laarman Lab, this hybrid technology combines an industrial multiple axis robot with a welding machine. The resulting material is a printed 3D metal that can be shaped in different ways. Several types of metals can be processed with this technology allowing designers to create different solutions with a particular aesthetical language.

Figure 13. MX3D - Kingdom Mutantis.

Magnetic Fibres
Kingdom Mutantis
This is a project undertaken by the designer Lilian Dedio. Arranging magnetic components in different patterns inside a textile, the material gains life with the aid of media and electronics. When the magnet reacts to a stimulus, the textile begins to move creating a dynamic behavior. The visible part of the magnets over the textile creates also a unique aesthetical language that changes over and over when the entire material is in movement.

Figure 14. Magnetic Fibres - Kingdom Mutantis.

Conclusion

In this pictorial, we provided a classification for the DIY-Materials based on the analysis of above 150 DIY- Materials cases. This classification helps to understand what kind of sources designers use as a starting point for materials development. Looking closer to those sources, we discovered that the designers who embarked on a process of self-production of materials, used elements from the world of plants and vegetables, the world of animals and the world of minerals. Also, we discovered that designers use waste as raw sources as well. In particular, scraps from industrial processes. It is possible to obtain DIY-Materials from a wide variety of sources. It should be emphasized that although we present five kingdoms of DIY-Materials, there are many cases that fall under two or more different kingdoms. In other words, the borders between these kingdoms are not strict but loose.

We believe that the presented classification with five distinct kingdoms can trigger new ideas for design research and practice by providing an entry point to develop a strategy for DIY-Materials. The classification can further contribute to the experiential knowledge that a designer acquires when embarks into a material development, as it provides different insights on particular qualities and properties that the materials inside a kingdom collectively share.

In the future, we would like to analyze these categories further to provide a systematic, step by step DIY-Materials approaches, based on the material source at hand.

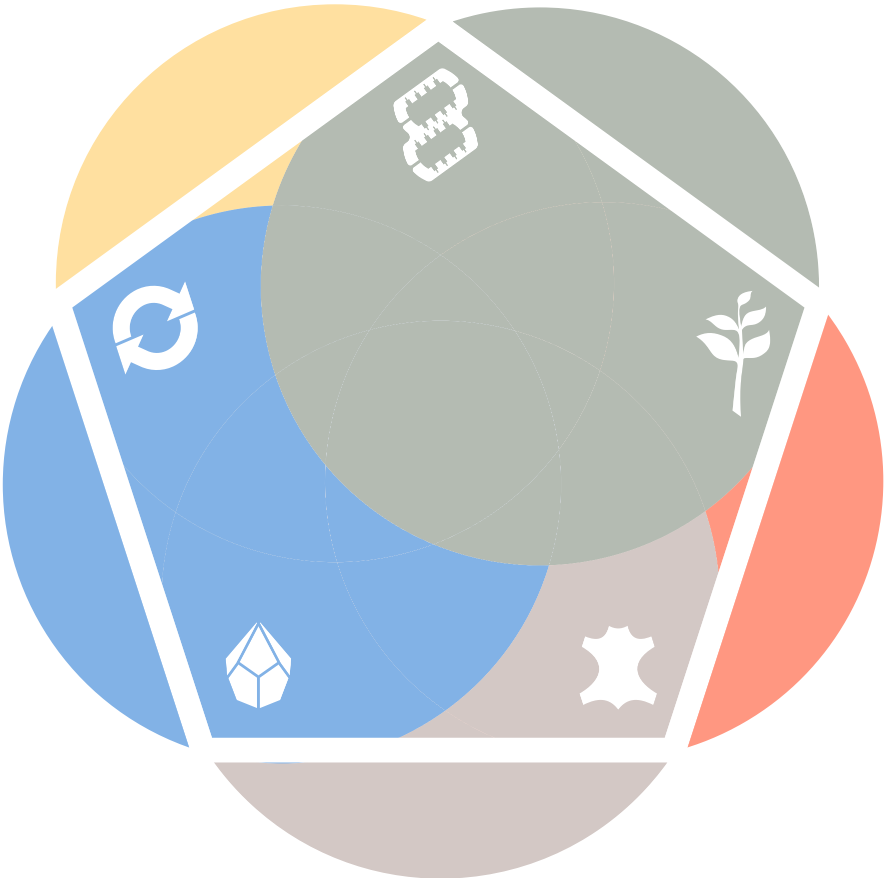

Figure 15. Some cases can fall under two or more categories.

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Links to webstites of selected cases

Kingdom Vegetabile
- Autarchy (http://www.formafantasma.com/autarchy)
- Agar Plasticity (https://www.kosuke-araki.com/agarplasticity).

Kingdom Animale
- Hidden Beauty (http://www.gutedort.de/)
- Coleoptera (http://www.aagjehoekstra.nl/coleoptera.php).

Kingdom Lapideum
- Marwoolus (http://marcoguazzini.com/products/marwoolus-2/).
- Baloon Bowls (http://www.maartendeceulaer.com/Balloon-Bowls-process),

Kingdom Recuperavit
- Sea Chair Project (http://www.studioswine.com/sea-chair/).
- Decafé (http://www.raullauri.com/).

Kingdom Recuperavit
- MX3D (http://mx3d.com/projects/metal/)
- Magnetic Fibres (http://www.hfg-offenbach.de/en/pages/institute-for-materialdesign-imd#about).

Developing Future Wearable Concepts using Archival Research and E-textiles

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Abstract

This paper reflects upon an interdisciplinary design research project ‘Electric Corset and Other Future Histories’ developed by a creative team of design practitioners from the fields of textile, fashion and, product design. The investigation is being undertaken in collaboration with the Nottingham City Museums and Galleries whereby access to their archive of historical garments and accessories is facilitated through working closely with the curator of the Costume and Textile Collection. The aim of the research is to convey the value of accessing archives; the potential role for items of material culture from past lives to inform e-textiles and wearable concepts of the future.

Based on the necessarily limited physical access to the archival materials, the research team has identified a unique practice-led research process that has informed the development of a number of outcomes that are both exploratory and experiential in character. This paper reports on two outputs that were developed as part of the project: an artistic film developed using collage and moulage techniques with textile materials, images of dress wear pieces from the archive, integrated with e-textile equipment; and two pocket prototypes, where pattern cutting and e-textile design knowledge were brought together. Both examples aimed to visually communicate the methods and technologies involved by reflecting the different embodied knowledge and skills involved, e.g. in recording, designing, making and interacting with fashion and textile materials.

The two outputs demonstrate the benefits of working with archives of material culture and how the modular nature of historical dress can inspire new, interactive relationships between garments, bodies and accessories. Future work aims to develop this process further by creating a collection of networked garment toiles for exhibition, where audiences will be invited to engage physically with these items to experience the overall fashion and electronic design and construction process.

Keywords

archival research; electronic textiles; visual communication; embodied knowledge.

The Electric Corset and other Future Histories is an interdisciplinary design research project which has consisted of two primary research phases since October 2014. The research team consists of the disciplines of textile design, product design and fashion. The project was inspired initially by an advert for Dr.Scott’s electric corsets in 1883, which exhibited benefits to promoting health and wellbeing for Women ‘in all stations of life’ (Art and Picture Collection 2014). The corset illustrated in figure 1. was designed scientifically with electro-magnetic technologies to improve women’s health and wellbeing. Its construction combined the aesthetical, physical appearance of the corset with the anatomy of the body to communicate cures for conditions such as backache (which became a common issue experienced by wearers). The advert represented a strong wearable innovation of the past enabling the Electric Corset project to investigate interdisciplinary approaches to wearable concept designs using electronic textiles. The project is interested in the social characteristics of dress-wear and illustrating the wealth of historical costume archive resources to developing future wearable concepts. It also particularly views its relationship to the wearer as an important factor, especially when designing for future wearables that integrate electronics and functionally active elements.

Fig 1. The advert of Dr.Scott’s Electric Corset which represented a strong wearable innovation of the past aimed to support women ‘in all stations of life’ (Art and Picture Collection 2014).

Uptake of Electronic Textiles as Wearables

One criticism of the uptake of electronic textiles and wearable technology is the acceptance of it as an everyday wardrobe piece. Dunne (2010) has argued that its acceptance as a functional garment piece is not entirely down to issues with technology, which have been previously focused on by Matilla (2006), Langenhoven (2007) and Cork et al (2013) in developing smart clothing applications for niche level sectors such as healthcare, aerospace and military. Page (2015) on the other hand examines the lack of uptake of wearable devices from a marketing point of view, stating that it is a lucrative market with a potential to having an impact on emerging digital debates such as the Internet of Things. A Cisco ISBG report (2011) demonstrates a huge opening for wearable innovations to succeed particularly since it has been predicted that by 2020 more than 50 billion devices will be connected via the internet. However commercially to date, sales figures have been low and the cost of wearable devices priced too high for the average consumer to adopt and use as an item piece that is similar to those we find within our everyday wardrobe and accessories. On top of this, current smart garments and devices have appeared gimmicky and side-lined to being represented largely in sectors such as sportswear or as novel catwalk pieces, those of which have been illustrated recently by Ralph Lauren (2016) and Cute Circuit (Seymour 2008).

The Electric Corset Project

The Electric Corset's focus to investigate how the uptake of electronic textiles can be enhanced further, responds to existing research in develop new alternatives to wearing and experiencing the potential of wearable innovations. Tomico and Wilde (2016) respond to the call for new experiential methods and real world research that address the third paradigm of human-computer interaction (HCI). Their approach enlists the qualities found within theatre design and participatory design approaches to envisaging new ways in which the body can inform the design and uptake of wearables. The third paradigm of HCI challenges the existing positivist traditions towards tackling the qualitative and holistic qualities that it inherently entails (Bardzell et al 2014). According to Jurmu et al (2015), this new orientation has drawn in researchers from a number of backgrounds and traditions including social sciences, architecture and industrial design.

The Electric Corset seeks to adopt more designerly ways of integrating electronics with wearable design and employs in its approach explorative and experiential research methods. Creativity in art and design is often portrayed as a result of artists and designers becoming freed from the constraints from hours of technical skill and know-how associated with craftsmanship (Sennett 2008). In the Electric Corset, we build upon Sennett's freedom and room to explore and co-create new wearable innovations and harness the term 'conviviality' coined by Illich which describes the autonomy of person becoming creative amongst other people within their environment (Illich 1973). Doorst and Cross (2001:435-36) help explain the pre-conception further in the position of the designer being surprised by solutions found within the design process, which leads to a creative leap, rather than a routine or set of default decisions. Townsend and Neiderrer, 2016 suggest that the new developments found within innovation are often due to incremental changes to the way existing technologies are mediated via the hand and computer. This response situates the Electric Corset to consider approaches that are perhaps transparent (Atatac 2016) and reflect deconstructive and reconstructive research methods found in fashion clothing construction (Lindqvist 2015).

The Electric Corset project responds to the current focuses that address situatedness of technologies and qualitative aspects of use within the third paradigm of HCI. It also contributes to need to enhance the uptake of wearable innovations and builds upon the existing research that identifies the need for further research from a fashion perspective (Stead et al 2004). The paper will illustrate the process of how two outcomes from the research process have been created to date within the project. It particularly examines the wealth of the archive collection used as a resource to support the research team developing wearable concepts and focuses on how the two distinctly different outcomes that are produced from the project suggest the open possibilities for which to envisaged future wearable concept designs that are open, playful and exploratory. The paper will conclude with an ongoing direction of the research project including a continuation of the research process towards developing a collection of networked toiles for future exhibit.

Sourcing from Archive Costume Collections

The research team collaborated with the Nottingham Museums Collections based at Newstead Abbey in Nottinghamshire to source items of historical costume wear. This initiative to visit the costume collections began late 2014; co-ordinating with a costume and archive curator based at Newstead Abbey. The visit included a number of item pieces being captured by the research team in their individual boxes with attached notes that described their origins. Amongst the items as shown in figure 2. included: a white twill ('jean') woman's corset (1800-1810), a woman's dress collar, embellished with shells and glass beads (1920-30), detachable men's starched linen shirt collars (1850 -1952) and a footman's livery coat (1890-1910).

The sourcing of item pieces from the archive prompted the research team to identify possible themes of interest to explore as part of a workshop session. These themes that had emerged from the visit to the archives included the functionality of the garment pieces, care and maintenance, modularity and layering (Kettley et al 2015). Extended themes upon which were found from the archives identified also the loosely defined conceptual spaces between clothing and the body and adornment as a site for creative product development (Townsend and Neidderer 2016). The significance of these themes derived from the visit to archives would initiate a practical exploration in a workshop involving the research team with a number of materials to guide the research process.

Fig 2. The items selected from the Nottingham Costume Collections at Newstead Abbey. From left: A footman's livery coat (1890-1910), a women's dress collar and men's starched linen shirt collars (1850-1952) and a white twill jean woman's corset (1800-1810)

Workshop Context

A workshop was arranged amongst the research team to experiment with the research material images gathered from the archive costume collection along with textile fabrics, electronic components and drawing media. Amongst these workshop items included secondary research materials such as books on fashionable technology and textile technology and full and half scale mannequins to drape textile materials and electronic circuits on to. The variety of equipment brought into the workshop was to support as much as possible a creatively open and explorative process for the research team to fully embody the research context of experimenting with archive resources.

Collage and Moulage Techniques

A hands-on approach involved using methods such as sketching and drawing to emphasise points of interests found in the images of the archive pieces. Other techniques included enlarging images of collection pieces to imitate human scale and placing these freely around the mannequins. This ensued a collage process to unfold on behalf of the research team by layering images, otherwise known as assemblage, over textile fabrics and draping them simultaneously onto the mannequins. According to Butler-Kisber and Poldma (2011), collage making and concept mapping can become useful tools to informing experiential research approaches. They further suggest that approaches that reflect collage and moulage processes help demonstrate how experiential ways of knowing and understanding or approaches that include tangible doing activities are a means of making tacit ideas explicit. It further helps both research practitioners and audiences identify possible insights. Friedman further claims that "the key to learning is linking practice to the critical analysis that transforms experience into knowledge" (1997: 18). The approach employed by the research team became evidently a viable method for translating two-dimensional concepts into three-dimensional forms as seen in figure 3. This was one aspect, where the role of collage and moulage became valuable tools to providing an opening for research teams to progress the work further into tangible and experiential forms. It further informed the research team to bring in other experimental prototypes to be placed on the body, in particularly electronic circuits.

Fig 3. From left: Moulage and collage process with mixed media, three-dimensional working on the stand with electronics and mixed media and textile materials experimented with in the workshop.

Electronic Prototyping Circuits

Electronic components were used for their readiness to be made into prototype circuits and similarly placed on top of or adjacent to other draped pieces of collaged work to replicate where zips and fastenings would exist in garment pieces. At first, the look and feel of electronic components where examined by the research team to assess their compatibility to being placed in pockets and linings which were drawn out by the research team during the initial stages of the workshop session. Certain materiality issues became apparent during this process particularly between the hard and soft characteristics of the electronic components and connectors with soft textile fabrics and paper sketches. The juxtaposition however of these materials enabled the research team to work around the constraints to their advantage. In particular, the ease of creating simple electronic circuits guided the research team to make prototype circuits that could be draped and collaged alongside other pieces of work on the stand. This process ensued by the research team reflected Schön's (1983) description of the professional design in action with materials citing that the process became a conversation with materials and that is subsequently guided the designer in their conceptual meaning making development of the work in progress. The research team found that at times it wasn't entirely necessary for the circuits to work but enough to simply explore the shape and form of electronic textiles and their possible placements and locations on top of the research sketches and textile materials. This however was a process that went back and forth and the materials on hand including the electronics became simply amenable to be transferred quickly into other pieces of work. This demonstrated the open potential of the prototype circuits and their flexibility of being used to instrumental guide similar research processes found in textile design that were emerging throughout the workshop. A development made on behalf of the research team in response to using the electronics was the potential it then offered to evidencing the interactions between the material processes, especially since some of the electronic circuits had introduced a functional element that needed to be captured.

Film Making

The advantages of making prototype circuits enabled the research team to introduce film making as a method for capturing the now interactive and lively pieces of collaged work. Small recordings were captured by the research team from two perspectives. The first would capture the interactions between the research team members working on particular and sometimes individual processes. Adjacent to this image is the second perspective which captured a piece of work that was working. This piece involved an electroluminescent (EL) wire being woven into a textile and turned on. The film captured the EL wire pulsating at different speeds, which to the surprise of the research team, reflected the original advert of Dr. Scott's Electric Corset. These two perspectives shared of the use of film illustrated to the research team an alternative to evidencing the hands-on activities in the workshop session (Kettley et al. 2015). It opened a new way in evidencing the embodied research process but also became valuable for the next stage of the project to showcasing outcomes of the workshop and use of the archive costume collection.

Crafting Anatomies Exhibition

The Crafting Anatomies exhibition[1] held at Nottingham Trent University gave an opportunity for the research team to exhibit the work to date. The film making approach was re-visited by the research team to convey an artistic impression of the workshop outputs. Butler-Kisber and Poldma (2011) claim that there is relatively little research that addresses the authorship of the arts-informed research process with collage. One of challenges towards developing a film for exhibit was to in some way leave it open and exploratory enough for audiences to interpret for themselves the value of the work. It remained a focus, however on behalf of the research team to illustrate artistic talent, especially since this had developed out of creative practice and is a form of confidence and learning development shown explicitly in a visual way by the research team. Promislow (2005) exhibits a number of collage inquiries where this reflexive knowledge (Hertz 1996) has emerged and been explicitly shown.

The research team compiled a number of resources from their collections from the workshop which included films, photos, toiles and sketches. The embodied and experiential process from the workshop was iterated within the development of the film, harnessing now the potential of drawing from multiple resources to develop a key narrative and depiction of the work in progress. Depicting the narrative of the workshop was extremely crucial and each of the frames created for the film were intended to be pieces of work in their own right (see figure 4. for examples). This contributed to the storytelling element of the film, drawing from excerpts of texts taken from books, the short films from the workshop and original photos of the archive location at Newstead Abbey. Fluidity and fullness became themes identified as being useful to refer to in the process to continually feedback to the original source of inspiration which was the archives. This emphasis developed the process of producing this research outcome into a meaningful and reflexive process on behalf of the research team seeking to locate their own individuality and contribution to the process whilst also managing the streams of multi-layered pieces of work from other areas from the workshop to feel at best, equal with the emotional connection felt on behalf of the research team.

The film was exhibited alongside three original pieces from the archive which were encased in tightly sealed boxes with acid paper to avoid contamination and harm (see figure 4 for exhibition set up). The film which was mounted on the wall and situated between the archive pieces, fulfilled the narrative of the research project and openly invited audiences of the exhibition to view

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[1] Crafting Anatomies: Material, performance, identity (2015) exhibition (7 Jan-4 Feb) and symposium (30th Jan) at Nottingham Trent University, Curated by Katherine Townsend, Rhian Solomon and Amanda Briggs-Goode.

outcomes of a workshop that were intended to demonstrate potential and future direction. This notion of openness brought together distant concepts between archive resources and electronic components, addressing a number of valuable issues that included democracy, identity and worth; connected to both contexts that involved archive costume collections and electronic textiles as accepted items of dress wear. A continuous development of this research process has since been developed on behalf of the research team, in particularly adapting the nature and acceptance of toiles as a way to path making (Ingold 2013) and understanding modular systems of dressing.

Fig 4. From top left to bottom right: Frames taken from the film which illustrated the workshop development and the final presentation of the film positioned with original garment pieces from the archive costume collection.

Identifying New Items of Dress

The second iteration of the research project led the research team to re-visit the archive costume collection to identify new items for further inquiry. Some of the items that were chosen from the archive costume collection included item separates from both men and women, including delicately adorned pieces such as lace collars and chatelaines and functional items such as spats, gaters and oversized pockets. Our research practice from the previous investigation had led us to question further the possibility of how to engage with participants especially with archival costume materials. We had also discovered from our previous research output, the necessity to construct a personal narrative. The pieces selected from the archives were items that would typically be found to support other modes of dressing and more commonly these pieces were found to have been stored under several layers of clothing. For example, in figure 5, the display of lace collars would perhaps have been used to adorn due to their decorative affordances, whilst the gentlemen's spats and gaters would be viewed as protective wear. The deep pockets in what appears to be a muslin material reminisces utility wear worn either on top of aprons due their ties to wrap round the waist of the body. Bernard Rudofsky described men's fashion as 'fossilised ornaments' that once had reasons for being (Rudofsky, 1947: 122). It is believed that these items collected at the archives once belonged to a greater value and that since the evolution of clothing, in particular wearables innovations with electronics, we can now seek to appreciate not just their original purpose but to shed light and new reason and narrative towards their use that perhaps previously, did not quite exist.

Fig 5. A selection of new items captured at the second visit to the archive costume collection. New additions to investigate included item separates found to have been possibly worn or layered underneath garments to either adorn or protect parts of clothing.

Mock-Up of Toiles

A mock-up of toiles was created from the visit under the preliminary category understood by the research team as dress separates. Making the toiles became instrumental to furthering our inquiry into the direction of conceptual mapping for designing with electronics. The simple detachments constructed on behalf of the research team, in particular a textile designer and a pattern cutter became a simple and effective way to quickly manage how perhaps the items of dress wear could be potentially linked to one another. The simplicity of the toiles reminded the research team of the work of Martin Margiela (Hodge and Mears 2006), using non-luxurious fabrics, typically used in the fashion development process such as calico or muslin to deconstruct and re-construct accordingly to the constraints of the body. Bourne out of this interpretation, the research team identified that the toiles themselves would play a role in becoming sacrificial, especially since the following stage would involve experimenting with electronics, this time with a promise of attempting to fully integrate them as part of the design.

Experimentation with Toiles and Electronics

An experimentation of the toiles continued with observing how potential wearers would interact with them as pieces and small short videos were captured of possible scenarios including filling the pockets with objects. The conceptual mapping continued between both digital and hand processes. The electronics were prototyped and placed more intimately in places of the toiles where interactions would take form. For example, LEDs were used to illustrate a simple capacitive switch, which when the hands would reach to button the collar, the proposed buttoning action would initiate an LED being turned on. The research team identified that materiality issues, experienced from the first iteration of the research project in the workshop had arisen again. More so, the research team needed to the consider shape and fit and the components themselves weren’t entirely flexible. Out of the selection of toiles, the research team understood that they had plenty of material to draw from and develop and the decision to select a dress item to develop was difficult but it became clear that managing the expectations and refining the process to benefit the future development of wearable concepts was significant. The research team chose two toile pockets to be developed further and to investigate more rigorously their potential to be integrated with electronics.

Theatre in Design

The pocket prototypes produced by the research team employed simple e-textile circuitry knowledge acquired from a previous e-textile workshop (Glazzard et al 2015), amongst other interactions that included making with e-textiles that had guided and given confidence to the research team to return to this knowledge and apply it to the project. First, the pocket prototypes were selected from a session, that invited potential wearers to try on or at least improvise as to how they could have been worn. The improvisation was facilitated on behalf of a textile designer in the research team, who had previously attended a summer school workshop based on incorporating theatre in design approaches to participatory design research contexts. The textile designer, drew from a process from the summer school workshop that she believed could enhance the design research process which was titled: Potato Theatre. The Potato Theatre enlisted a technique for user interaction, that employed approaches situated in bodystorming techniques (Oulasvirta et al 2003). Participants in the session with the toiles were asked to simple improvise with the toiles as to how they were worn and were guided by the textile designer to envisaged how else they could be worn (Figure.6). The images captured from the session with the participants were translated into digital pieces of work, where the textile designer circled out zones of interactions as well as trying to sketch out possible future scenarios that would guide what types of electronics to use. These sketches had built upon the decision to select the toiles to modify and include electronic circuits.

Fig 6. The session involving improvisational techniques informed by bodystorming and potato theatre. Participants were asked to envisaged how the toiles would be worn on the body. They were also further asked to explore alternatives to how they perhaps could be worn.

Pocket Prototypes

The two toile pockets underwent a process of which the research team had to begin deconstructing the toile pockets to understand its method of construction. A pattern cutter was invited to guide this process and simple step-by-step process was given to the textile designer of the research team to continue with. The textile designer was a complete novice to pattern cutting and apart from having basic knowledge of electronic circuits, her initial emotional feelings upon learning a new skill was completely overwhelming. Apart from this, the step-by-step process led the textile designer (responsible for creating the pockets) to develop the two toile pockets ready for the next stage which involved integrating simple e-textile circuits. The resources on hand to the research team and the textile designer meant that simple e-textile switches could be crafted. A discussion with another research team member, experienced in product design prompted the design of a conductive ring that when worn and placed into one of the pocket prototypes would initiate a sequence that would turn on two different LEDs. A secondary design development discussed between the textile designer and product designer suggested how objects being filled in one of the pockets would instead of initiating an LED to turn on, would instead reversely break the circuit and switch off LEDs attached by press-studs. The reversal of this process had prompted the research team to identify alternative uses to electronics, whereby existing products would normally be powered and switched on to become illuminating and functional. However, in this prototype idea, it had suggested that it perhaps works the other way too and that simply creating functional and illuminating textiles should not limit the assumption of how the wearer could potentially wear it or use it. The final prototypes showcased at the end of this process were illustrated by a sequence of how perhaps they would be used, with what and by whom (Figure.7). The research had found that this ordering and sense of organization had promised a new direction for the project to envisage a wearable concept where simple e-textile circuity means could facilitate the joining up and connection of other items of dress to inform a full wearable dress system.

Fig 7. The final prototypes of the toile pockets with electronic circuits. The images depicted are used to illustrate a sequential process of how the wearer who interact with each toile pocket and how as a result this would initiate an output response.

Reflections on Outputs

A surprising development found on behalf of the research team and the textile designer, was the pace in which was involved in making the toile pockets and how something simple and small could lead to a dramatic effect using only the available resources to them. In some way, for the textile designer, it made them aware of the advantages to messy processes and that drawing from simple tools to be used as guidelines to informing collaborative practice between disciplines was albeit a beneficial and worthwhile approach. The subsequent impact of this had opened to them the possibilities and range of work, where open design is concerned, in particularly for their own personal research. Eco's response to open design as a methodology can be found in Kettley's argument on hyper functionality and its role in product design (2012). Kettley cites the work of Eco, in particularly how he refers to open design in the context of chemical reactions. This process claimed by Eco (1989), performs an act whereby bringing order to a system can lead to closing down a number of potential paths, whereas the promise of creating possible paths for molecules could subsequently lead to a symbiosis between other chemical reactions. The Electric Corset which has led to evaluating two iterations of the research process and two outcomes of the film has demonstrated a change upon what occurs in the moment in practice, which ultimately guides the research team both as a group and individually to discover new paths in which to emphasise on the role of using archival research as well as new research materials in the form of electronic textiles.

Embodying New Media for Engagement

The state of affairs concerning new alternatives to exhibited experiential research is felt in more recent examples where the outputs use similar approaches found in the Electric Corset. For example, a recent exhibited hosted at the Somerset house in London, showcased a digitally immersive space in which to experience the new album created by the artist songwriter Björk. The exhibition titled: Björk: Digital, showcased early 2016 provided a virtual reality space for fans to enter rooms of experience mediated by state-of-the-art technology and virtual reality systems. The immersive rooms, brings together the people listening to her music in a sensorial and tangible way, using artistically created music videos for people at the exhibition to practically step into. Another example from a different point of view, which similar mediates the issue around materiality, is in the example shared by Nick Knight in his recent collaboration with fashion label Alyx (2016). A catalogue film was produced on behalf of the collaboration, drawing from Nick Knight's background expertise in visual methods, particularly as a photographer to develop an interactive portfolio. The portfolio of the collection, showed by from above by what appears to be through the lens of a viewer, with only their hands being made visible to turn each page. The theme of continuity arises from this piece of work specifically how its pace adds to the build-up of the narrative of the fashion collection. From an alternative fashion research point of view, Piper's (2016) research into constructing a novel weave methodology is portrayed through the use of a film, which includes both digital and hand processes from research development, in particularly sketches. Her evidencing of practical knowledge gained through developing research sketching and material explorations resembles the same approach used in the Electric Corset to create the film for the Crafting Anatomies exhibition.

Conviviality

What can be deduced from these examples, is how materiality is being explored through different media. In the Electric Corset, we are open to learning from distinctly different practices and seek to develop an interdisciplinary research approach to developing new wearable innovations. The conditions in which the project sought to build from, which include the archives as an integral source of inspiration throughout the research has developed the research into understanding more fully the impact of the research process on a potential audience. We return to the original debate around authorship and perhaps how this can be developed into a co-authored relationship under the instruction and guidance illustrated by Illich's conviviality meaning. We appreciate that in maintaining our credibility as researchers from our own design backgrounds, that our outcomes to date can facilitate a dialogue between viewer and artist. Moreover, we build upon Illich's (1973) reference to people needing not to only obtain things but to above all have the freedom to make things among which they can live and give shape to according to their own tastes. The future direction of the Electric Corset attends to this new insight into learning from experience and the following work to be completed on behalf of the research team is about to begin.

Future Direction of the Electric Corset

The future direction of the Electric Corset project will focus on the development of a collection of networked toiles which build on the findings from the film and pocket outputs described above.[2] The toiles, consisting of three shirt-style calico jackets will form 'garment canvases' (Townsend 2011) for integrating different, separately constructed elements such as collars, dickeys, cuffs and pockets incorporating e-textile circuits. The term 'networked' has been used here to convey the notion of 'making contact' through technically enhanced functionality, facilitated through the toiles/ elements in response to different interventions by the wearer. These include the illumination of (LED) light patterns triggered by everyday embodied gestures, such as putting hands in pockets and adjusting collars and cuffs, all powered through hidden electronic connections and magnetic switches.

The networked toiles are the result of reflections on the experimental and experiential process to date by the research team and will consider factors such as participant engagement and presentation. The newly introduced factor of participant engagement will challenge the existing research methodology by introducing a new set of expectations, raised by the intuitive and deliberate actions of the general public/ others. The research team will continue to work collaboratively with the curator and archive collection, e-textiles, but with the aim of inviting new people with additional skills and expertise in interdisciplinary research methods to contribute to the research process, such as engineers, artists and conservationists.

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[2] The collection of network toiles is to be exhibited at the research through design conference between the 22-24th of March 2017. The conference will offer a platform for candidates to exhibit work in progress for audiences to engage and interact with in delegated rooms of interest. Full conference details can be found at: http://researchthroughdesign.org/2017/

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Textile Choreographies: Bridging Physical and Digital Domains in the Context of Architectural Design

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Keywords
Textiles Choreographies;
Architecture;
Motion Capture;
Physical-Digital;

Abstract

This paper addresses the topic of material engagement in the context of textiles and architectural design. Our aim is to propose an integrative interface based on elastic and non-elastic textile materials that uses motion capture devices as tool to translate physical performances into a digital workflow. It is an attempt to embed the material at the early stage of the design process in order to have a better understanding of how such material behaves by identifying its nuanced expressions.

Exploring the material performance suggests a more integrative design process that extends beyond digital simulation of the material by understanding real-time performance. This performative process, enables the designer(s) to creatively interact with the material, manipulate it, perceive its logic, eventually transform it and ultimately fabricate it.

Introduction

The Role of Movement as a Matter of Design

For Latour (2005), materials have their own agency regardless of the maker. They behave in particular ways and hold an involuntary agency that escapes certain forms of control. Textiles can be understood as adaptive and responsive materials that can embed a surface or a volume (such as clothes). These qualities make them different from other materials that are hard and possess little elasticity. However, the pliable property of textiles is also what constrains them, as it is not possible to achieve a stable textile structure.

The performativity of textiles is connected with the idea of transformation, of the notion that something continues to develp in action (see Fig. 1). At the same time, the body works as an agent that triggers the movement of textile. In this sense, we can say that the textile amplifies the body action by materializing the echoes of the movement.

Fig 1. Visualization of one action echoed in time. Transformation is in continuous development.

Delft University of Technology, The Netherlands

The idea of material as movement is not new. Several projects exist that address the topic of movement as material of designing interactive products or services (Svanæs; Schiphorst & Andersen; Jacucci et al.; Klooster & Overbeeke; Djajadiningrat et al.; Hummels et al.; Jensen; Larssen et al.; Fogtmann et al.; Antle et al.; Loke & Robertson; Ross & Wensveen; Wilde; Schiphorst; as cited in Loke & Robertson, 2011). According to Loke & Robertson (2011) such approaches include the use of the body to understand movement and communicate ideas, findings and to explore and evalute design concepts.

Our goal, however, is not to gain a bodily understanding of movement but to discover new spatial qualities when textiles are coupled with body movement. With the capacity to perform, textiles hold qualities of temporality that are transient, dynamic, and kinetic. As such, textiles can create architectural spaces that can be inhabited as they express a tactile spatial awareness shaped through the digital.

The value of movement in textiles also has to do with their capacity to adapt, to fold, or to create volume and shapes. This value is connected to the idea of textiles as a formless surface, as a shapeless material, that can become a structure as body movement gives form to the textile.

Considering Franz Erhard Walther's textile installations or Loïe Fuller performances, some evidence suggests that textiles can embed three-dimensional and spatial qualities through the body movement (Salter, as cited in Vallgårda, 2013).

Our research explores the spatial qualities of textiles to show how they might unfold a new kind of spatial expressions that has the potential to be adopted in architectural design. We propose a new method inspired by improvisational dance techniques, with the aim of suggesting new spatial expressions.

Bridging Physical and Virtual Domains Through Real Time Performance

Our method can be defined as a set of actions inspired in improvisation dance, motion capture and architecture computational design that provide us with both theoretic and practical ground from where to rethink both the textile design and architecture discipline. Loke & Robertson (2011) found that 'there is an interest in methods that focus on the felt experience or first-person perspective that are inspired by dance, performance or somatics'. Kirsch, 'argued that by exploring how we think through things, designs may draw upon our embodied, distributed, and situated cognition, and our 'physical-digital coordination' (in Hansen & Morrison, 2014, p. 29)

We started this practice-based investigation by engaging with textiles through body movement performances. The elastic textile neoprene (Fig 2.) works as a skin that embodies a shape, allowing for closer body interaction. We define this behavior as a skin structure. This textile works better when it is attached to a part of the body since its heaviness and stretchable properties tend to adapt to a surface. In exploring this textile, we sewed the edges of the piece of textile to create a sleeve for the arms to pass through, as we wanted to explore the choreography in groups of two people in order to grow in space.

Fig 2. Elastic textile neoprene

The lightweight textile polyester (Fig 3.), however, expands volume around the body, allowing for body interaction, which we define as a shell structure. This textile demands non-attachment to the body position, as it has the property to fill itself with air while moving around the body. Thus, it becomes more expressive when you hold it with your hands.

There are other similar methods described by researchers from different fields. Wilde (2010) describes a body-centric approach that places embodied experiences before language to propose a different kind of engagement with our bodies through a wearable device. Krish (2010) uses the body as a physical thinking tool.

Fig 3. Lightweight textile polyester

Fig 4. Marcel Duchamp's Nude Descending a Staircase No. 2 (1912). Photograph by unknow.

Fig 5. Eadweard Muybridge's Descending Stairs and Turning Around (left, photograph by unknown) compared to our own series of superposed frames revealing a hidden spatial textile-body movement (right).

Whilst Klemmer, Hartmann &Takayama (2006) investigate the role of the body in shaping human experience. In our case, the value of using the body within the design process lies on its capacity to perform movement and to express gestures in a very meaningful way in terms of form.

That potential of the body to express and to sketch forms in the space has been widely investigated by choreographers and architects as a way to inform their design processes respectively (Stathopoulou, 2011); Forsythe, Choreographic Objects, n.d.). However, little has been said about the potential of using textiles and the body in movement to inform an architectural form. Our findings suggest that each textile needs a different position in relation to the body in order to move and to express its spatial qualities (Fig 4. & Fig 5.).

Fig 6. Currently available 3D animation software allows us to echo action over time, hold it, and reproduce it as one single movement. As in Duchamp´s artwork, (Fig 4.) we attempt to depict the body in action.

Fig 7. Dancers interacting with the elastic textile neoprene.

Fig 8. Dancer interacting with the lightweight textile polyester.

Reflections on the Experiments from the First and Third Person Perspective

The value of using mixed perspectives within the design process has been acknowledged and defined by Smeenk, Tomico & van Turnhout (2016) as a novel framework for design that allows designers to use their own experience as a way to support the design process. We conducted a series of four iterations alternating between the first and third-person perspectives (Fig 9. & 10.) with the aim of understanding and revealing the architectural qualities of the textile-body performances. We understand the textile and the body as systems whereby both negotiate between each other.

Fig 9. A sequence of the first-person perspective.

As experts on body movement, we invited dancers to interact with textile materials through improvisational dance performances (Fig 6., 7. & 8). From their perspective, performing with a textile held or attached to them, makes them move differently as if they were not holding it. The qualities of the textiles such as elasticity, lightweight or pliability shape the way the body moves while at the same time, the textile mediates through the body when the latter inhabits the textile and creates a whole unit. As such, we define this interplay between the agenciality of the material and the agencialtiy of the body as a textile-body schema.

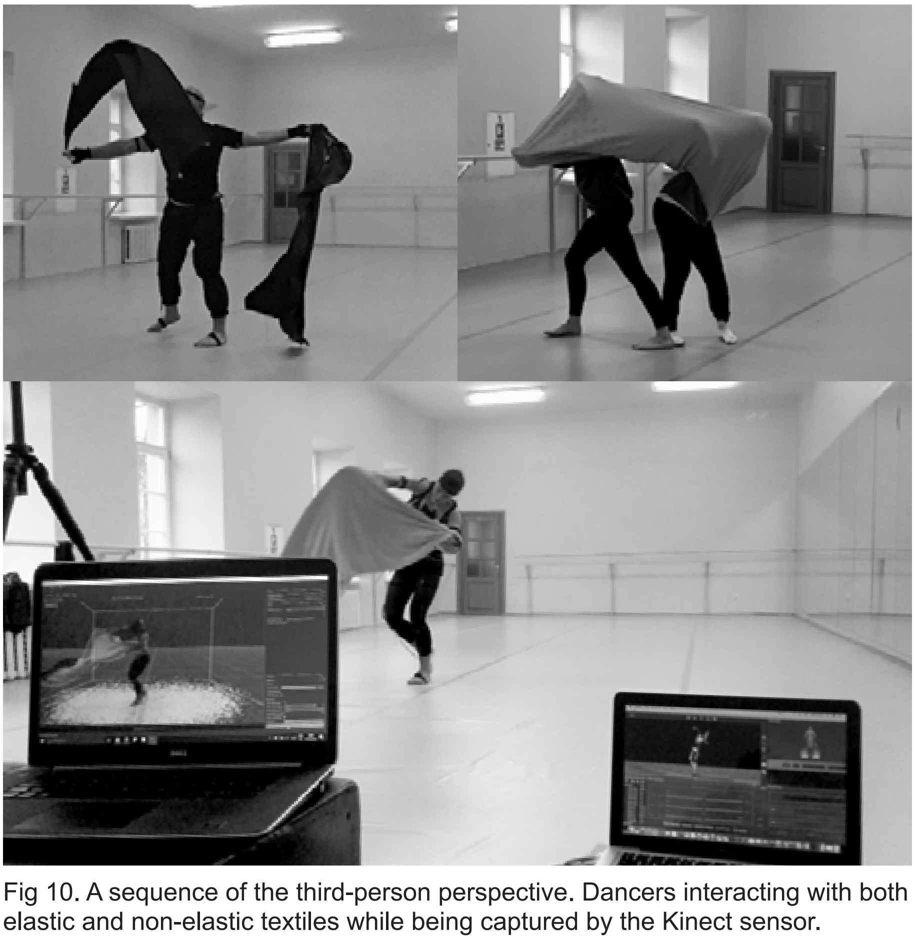

Fig 10. A sequence of the third-person perspective. Dancers interacting with both elastic and non-elastic textiles while being captured by the Kinect sensor.

Reflections on the Architectural Implications of the Textile-Body Schema

The choreographic experiments we carried out showed the potential of new material expressions revealing the three-dimensional spatial qualities of textiles arised from the textile-body schema. We strive to provide a digital toolset for designers to appropriate themselves of any physical body-textile context for digital design and investigate which spatial expressions could potentially emerge.

Within our workflow (Fig 11.) we work with a dematerialized textile-body in the form of a tiny particle matrix (Salazar, 2015) that can be transformed into digital architectural explorations (Fig 12.). Our set-up blends motion capture techniques of body-textile schema choreographies with digital modelling tools to facilitate fluent interaction across physical and digital realms (Gannon, 2014).

We can engage physicallly and digitally with textile material at the begining of the design process, generating creative feedback between our digital creation and our physical inputs in form of body-textile motion. It presents the opportunity to explore possible spatial implications of the performed actions by linking a rational digital design process to a more embodied, organic and intuitive approach (Fig 13.)

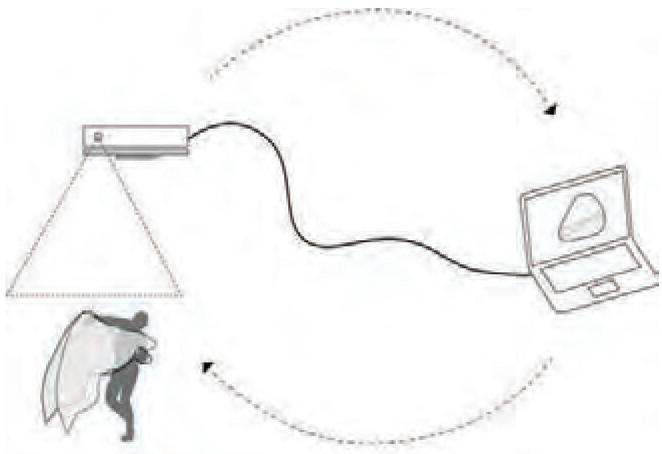

Fig 11. Motion capture set-up includes interface device mainly featured in the entertainment industry. The Kinect is used as a markerless sensor to translate motion into digital information.

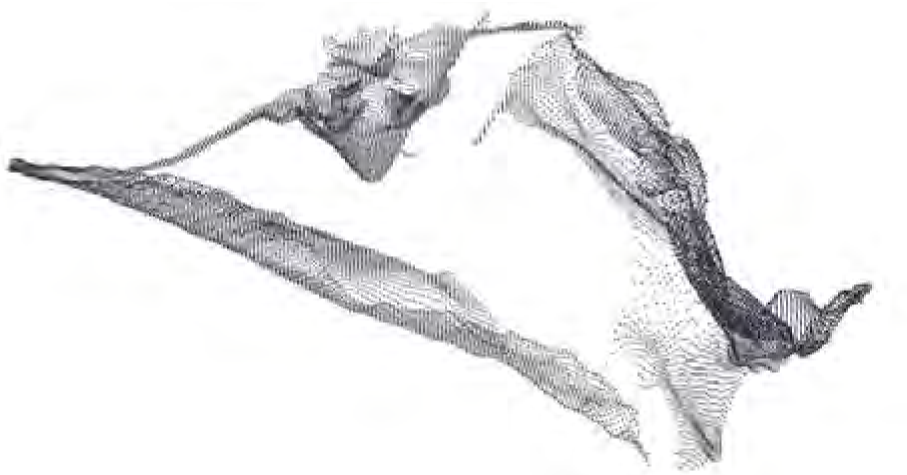

Fig 12. Data captured in the form of a point cloud (PC).

Fig 13. Digital visualisation of the movement echoed in one single frame.

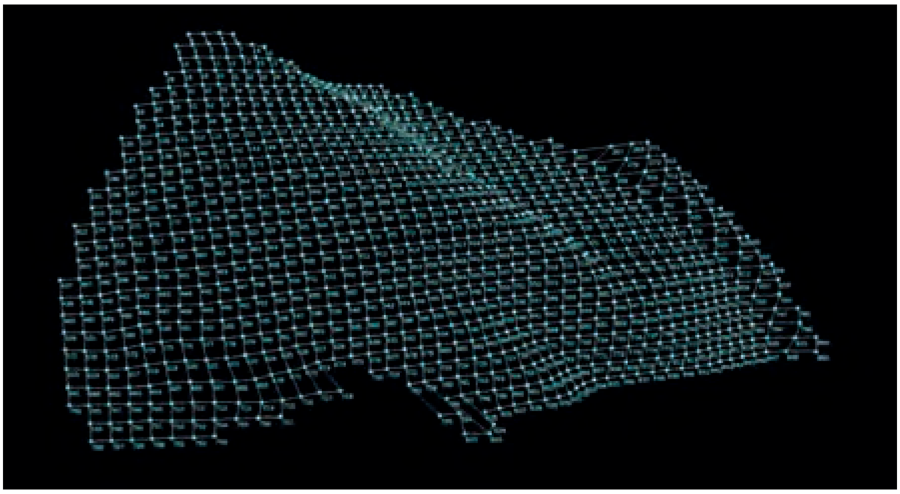

Fig 14. Point Cloud mesh obtained with Kinect and imported in SideFX Houdini. Digital information is manipulated to visualise textile-body expressions and analyse (right) them looking for architectural implications (below).

Fig 15. Houdini procedural pipeline defined to digitally model with the recorded data .

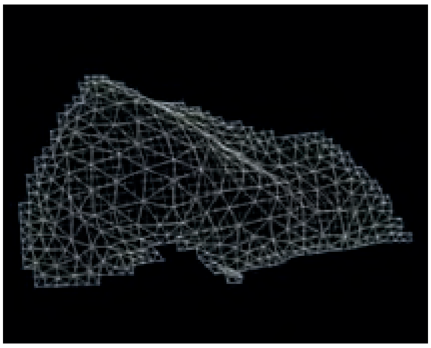

Fig 16. Original PCD-mesh parametrised with new scattered points.

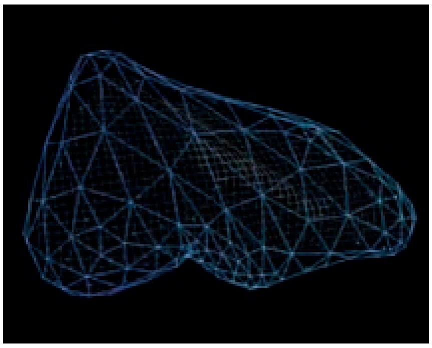

Fig 17. Volumetric modelling processes.

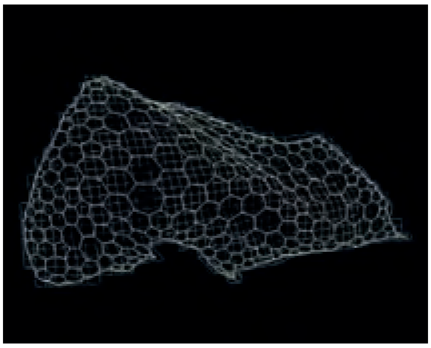

Fig 18. Retopology strategies.

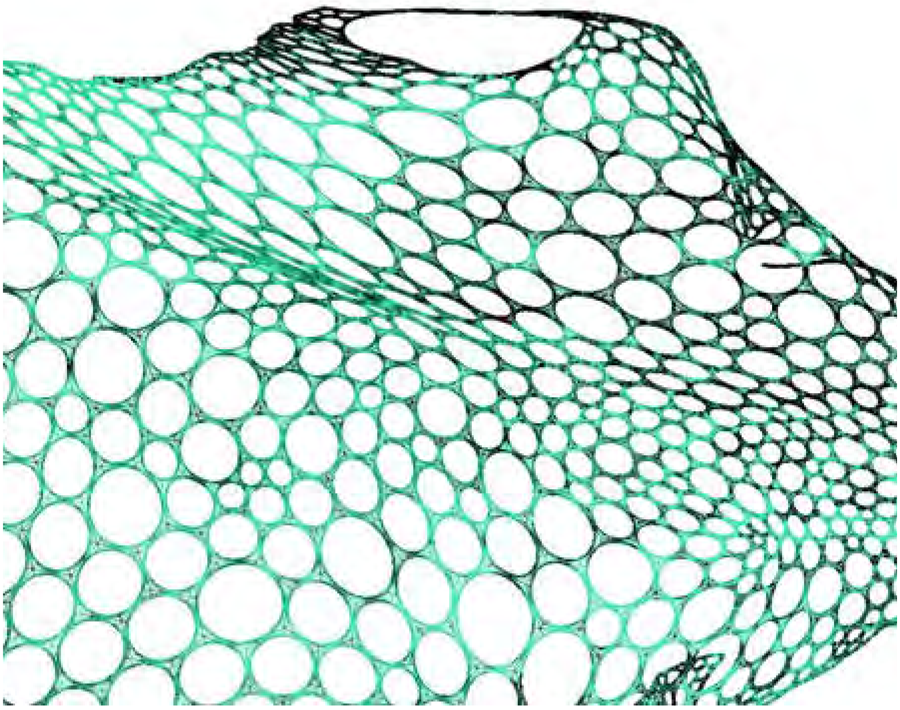

Fig 19. Retopologised mesh.

In the same way that textiles interact with the body in a specific manner, a particular digital technique needs to be defined in order to use the data as a matter of design. Procedural animation software SideFX Houdini offers the possibility to transform such motion data into volumetric or surface information. It produces a collection of morphologies whose generative conditions are explicitly linked to the performed textile-choreographies. This suggests that any action in the physical arena has a corresponding digital form that can be conveniently manipulated to make it architecturally meaningful.

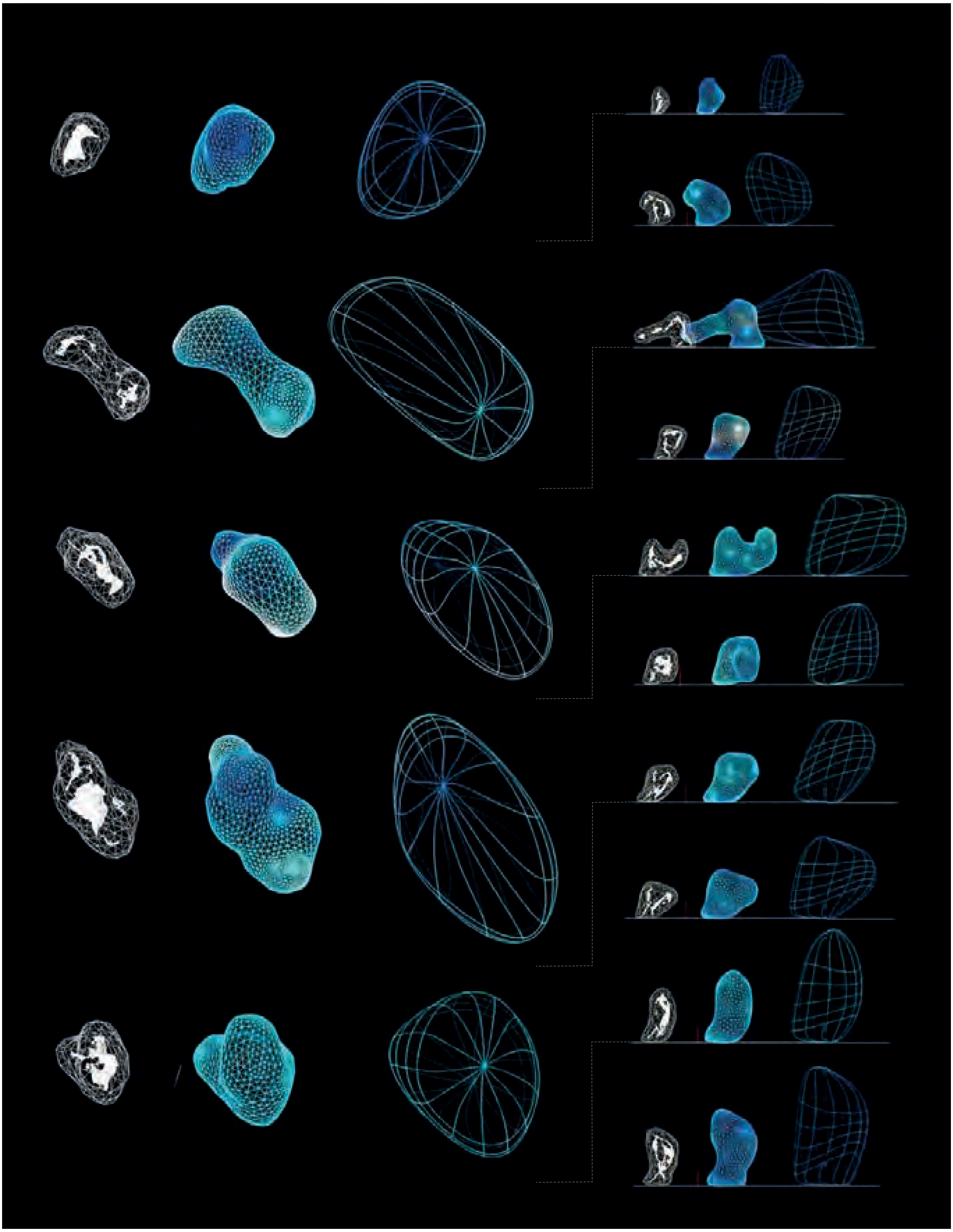

Fig 20. From physical action to digital morphogenesis. Textile-body performances captured are translated into a collection of morphologies by operating them at their near-field volumetric limits.

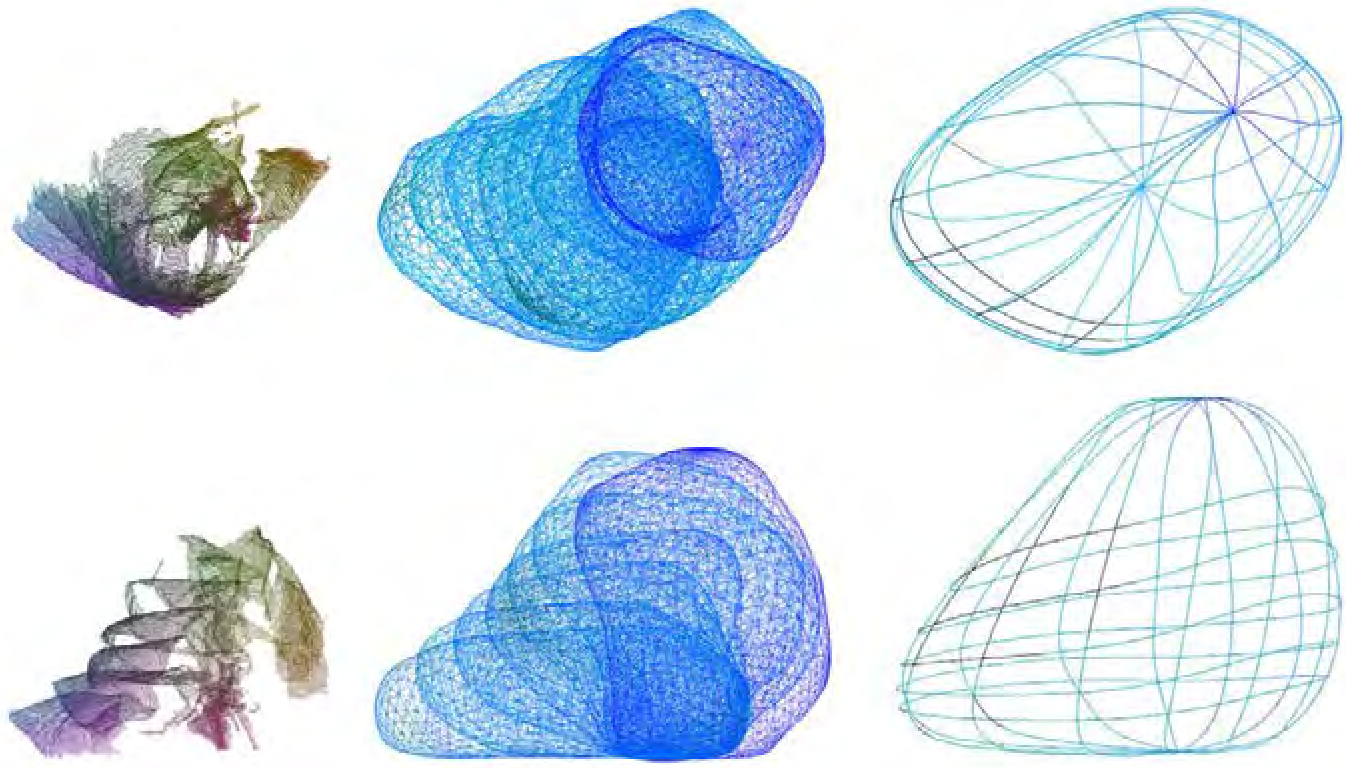

Fig 21. The proposed method presented in this paper offers the possibility to digitally shape not only a single moment of a particular action but a whole sequence of actions.

Discussion

We have presented an exploratory approach towards an architectural design that proposes an integrative interface, based on elastic and non-elastic textile materials, that uses a motion capture device as a tool to translate physical performances into the digital workflow.

The present approach offers a new perspective on how to engage with textile materials when combining the fields of textiles and architecture by introducing movement as an integral element of the design method. Other similar methods that use motion capture tools for the field of architecture and focuses on ‘the generation of form through movement and gestures’ (Hirschberg, Sayegh, Frühwirth & Zedlacher, (2006) do not contemplate the possibility of tracking the temporary and spatial qualities of textiles. We argue that our method fosters innovative understanding of textile spatial forms across physical and digital realms giving a voice to the material and the body while they collaborate in a form-giving process.

Moreover, the choreographic experiments results validate the aforementioned described integrative interface to enact soft spaces that can be translated, analysed and shaped through the digital domain in order to generate data to be used as a matter of design. The outcomes are a series of digital morphologies that may inform a fabrication process for architectural design.

Additional research will provide the possibility of exploiting the textile choreographies by manipulating the surface of the textiles and their position in relation to the body. Textile design techniques such as pleating, draping and sewing can enrich textile expressions allowing for a more meaningful interaction, while we gain a deeper awareness of our physical actions through their digital analysis.

Further developments comprise of fine tuning the physical-digital toolset we describe in this paper and to contribute, consequently, to an explicit understanding of the architectural potentials that could be obtained, by digital means, from the textile-body schema. In this way, we intend to ultimately incorporate them into the process, in order to address a particular design motivation.

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Radically Relational: Using Textiles As A Platform To Develop Methods For Embodied Design Processes

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Abstract

This position paper builds on textiles as a metaphor to explore the experiential knowledge observed through embodied design processes. In order to build understanding, we have tailored our tools and methods to support our explorations so far. As literature shows articulating our sensory experiences with materials is a challenging task. In order to support our investigations, in this paper we present a reflection on our diverse approaches to introduce tools that support us in interrogating how designers relate with materials, particularly textiles, and use their sensorial body to experience them during the creative process. We build on our previous research that identified relevant embodied process to textile selection, and reflect on how we have explored how sensing technology can augment and empower each of these phases, to support the design process. We conclude by discussing the learning outcomes from introducing such tools, in order to reflect on the future of our research.

Keywords

Embodied processes; Experiential knowledge; Immersive; Augmented; Mediated

Articulating our sensory experiences with materials is a challenging task (Obrist et al., 2013; Atkinson et al., 2016), but it is crucial for the creative process to unfold. Here we focus on a specific type of material, and we chose textiles, because as suggested by the iconic fashion designer Yohji Yamamoto “the fabric is alive and the real thrill lies in taming the tail of a living thing.” (Yamamoto, in Salter, 2014). Even before the possibility of developing alive, active and adaptive materials emerged, textiles were already performing and relating in such manner. Textiles are soft materials that respond actively to being touched or otherwise moved, and are generally worn close to our bodies, adapting to it. In this paper we use textiles as a metaphor to explore the experiential knowledge observed through embodied design practices.

The human race historically makes with their hands, and the level of specialisation of hand sensitivity and skills has been studied from diverse perspectives, such as philosophy (Noë, 2004), phenomenology (Ingold, 2013; Flusser, 2014), cognitive sciences (Kirsh, 2013), crafts (Sennett, 2008; Lederman & Klatzky, 1987), and more recently in human-computer interaction (Atkinson et al., 2013) and design (Petreca et al., 2015), just to mention a few. Particularly in the case of textiles, a framework has been proposed to look at the textile experience (Petreca et al., 2015), which is formed by 3 main touch behaviour types (*active hand*, *passive body*, and *active tool-hand*) and 3 tactile-based phases, as follows:

Situate describes the first experience with the material, it is the initial experience where designers, through a combination of touch behaviours, using hands and sometimes other parts of the body, first attempt to grasp a material’s properties.

Simulate is when designers after comprehending the material, start to play with the fabric in a creative manner. They put the material to a series of tests to explore different concepts. The body, or parts of it, is used as a platform for such simulations.

Stimulate characterizes the phase in which the designer goes beyond the physical properties of the material and initial concepts. At this moment the designer starts to envision complete new possibilities for the material. This phase involves the use of the entire body and the creation of metaphors to externalize more poetical and powerful material becomings, as well as subjectivities.

Here we build on this framework showing how we have explored how sensing technology could augment and empower these embodied processes. The prototypes included here are not yet a final solution, but experiments that show a proof-of-concept, which is that tools can be brought in to support the design process through enhancing and empowering embodied processes. Hence, results are not reported here[1], because the point is to reflect on how these tools help to understand and investigate the textile experience, by experimenting with these embodied processes previously identified.

This paper shows how with the tools we have selected what to represent about the fabric and about the body, and how these are tailored according to the level of focus that we wanted to work at: the finger, or the arm, or the whole body. These have happened mainly through two types of strategies:

1. Focusing: on the body part, on the characteristic of fabric you’ve decided at that moment, on the textile interaction (which may change – shift the focus by stressing one part or another), and/or on who is generating (myself, or another person).
2. Representing Sensation: in the projects we present here we have mostly prioritised one sensory modality, specifically visual, tactile, or auditory.

[1] Results can be found in discrete publications about each tool presented in this paper, namely: (Petreca, 2016; Yu, 2016; Saito, 2015).

This compilation of works show diverse approaches to introduce tools that supported investigations on how designers relate with materials, particularly textiles, and use their sensorial body to experience them during the creative process. With this, we complete the framework that was introduced with the 3 tactile-based phases of the textile experience, by saying how technology can empower that exploration. Finally, we discuss the learning outcomes from introducing such tools, in order to reflect on the future of our research.

The Pocket-Tool

Tactile experiences with textiles differ largely between individuals and the embodied processes (i.e. sensory and affective) by which designers select textiles are categorically overlooked by both designers and the industry, in favour of technical textile knowledge (Petreca et al., 2015). In the textile area, the sensory experience is crucial, especially for designers, who base their material choices heavily on feeling and tacit knowledge, that is, sensorial awareness build through experiences. We aim at further understanding this rich experience by investigating touch behaviour. We have developed the Pocket-Tool with the context of a textile fair in mind, as this is an intense moment of textile selection, where the number of textiles at display is overwhelming, and to make matters worse designers cannot take home samples from the fair, and have to wait until suppliers send them later. In this scenario, what do designers need to remember about the textile feel when back in their studios to share with their teams or to select a textile to order?

Device

To investigate further the touch behaviour when handling textiles we designed a research tool, the Pocket-tool (Petreca et al., 2016). The Pocket-tool (Figure 1) is built with Arduino-based technology and it comprises a set of six force sensitive resistors (1.75x1.5" sensing area), and correspondingly six different textiles (all white or cream to reduce variables and avoid colour effects on the experience) shaped in the form of a small pocket) within which the resistors can be inserted. As participants interact with the pockets they visualize lines being plotted (one corresponding to each textile pocket) on a display, which reveal the amount of pressure applied and captured by the resistors as they touch.

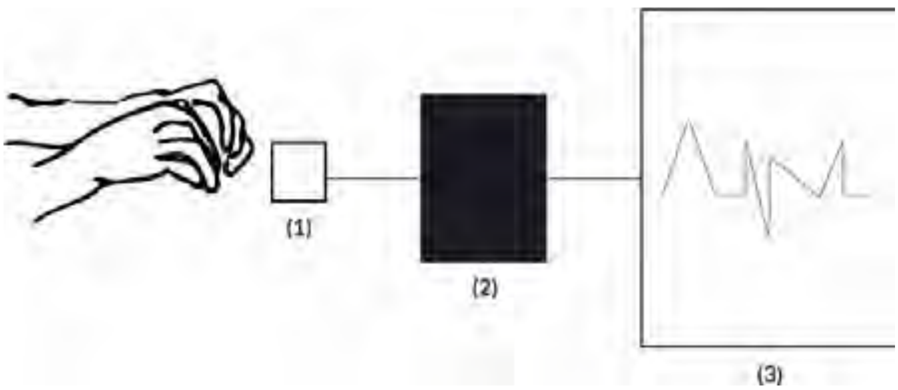

Fig 1. Schematics of the Pocket-Tool interaction, where (1) is a force sensitive resistor (“pressure sensor”), with 1.75x1.5” sensing area and is covered by a fabric pocket, (2) is the box holding the Arduino board and (3) represents the lines plotted as a result of the interaction.

In studies using this tool, participants were asked to find the fabric pocket that better represented a property defined by a verbal descriptor, which was suggested by the researchers. The verbal descriptors used were: smooth, rough, soft and hard.

Discovering what the body does

As reported previously (Petreca, 2016; Petreca et al., 2016), the use of the Pocket-tool was revealing in the sense that it allowed us to disrupt the way designers normally interact with textiles and helped in facilitating conversations around this experience, as they enabled the articulation of aspects that generally remain unspoken or unconscious. The use of the Pocket-tool contributed to our understanding that the textile touch is a multisensory experience, going much beyond the tactile appreciation with the hand manipulation only, and that this is a very complex experience to communicate (Petreca et al., 2016). Also, it revealed the importance of tacit knowledge in experiencing a textile during selection, as much of the aspects that remain unspoken are determinant for the decisions that designers make.

With the Pocket-tool designers revealed a focus on their bodily experience, which led to reflection and understanding of what they were doing. The mechanism of the Pocket-tool was based on the sensor measuring the interaction and providing a focused attention on the part of the body that is measured, as well as the feedback provided, which facilitates the understanding of the body part that is engaged. Hence, the Pocket-tool provided at the same time a top down and a bottom up process; top down because the person sees the graph and realises what the body is doing, and bottom up because as one focus on a body part being measured, there is reflection on what the body is doing, discovering what the body movement leads to in terms of emergent understanding from the interaction – about the fabric and about oneself.

This is related to the 'Situate' tactile-based phase, which is about the understanding one gets from the fabric and from oneself, and is emergent from the interaction between both. The Pocket-tool contributes to enhance those internal feedbacks that we have, the proprioceptive feedback that are very subtle, as if it was creating, or rather enabling a 6th sense of the experience, which comes from this focused attention. Finally, there are many possibilities in which this type of interaction could be further explored, since in terms of how the body is moving, one could work gradually (up-down) to explore how the body is experiencing from the local part to the full-body level.

The Haptic Sleeve

Online shopping for fashion has recently seen rapid expansion, but it is still facing the challenge of translating tactile experiences in an online environment (Perry et al., 2013). Textile-based products are classified as a high-involvement product category that needs to be evaluated through multi-sensory channels (i.e. touch, visual) (Workman, 2009). Touching fabrics is a multi-sensory, emotional, and psychological experience, which is of particular importance for both experts (Petreca et al., 2015, 2016) and non-experts (Atkinson et al., 2013, 2016; Cary, 2013) to appreciate and understand fabrics.

In efforts to understand how the textile touch might be mediated, previous research (Cary, 2013) tried to identify the gestural language that reflects the experience of textile touch. The main objective of this experiment was to see if people are able to tell from someone else manipulating a fabric how a fabric feels. Six gestures identified through interviews (Rubbing, Stroking, Squeezing, Lifting, Scratching and Pressing) were used to produce video clips. These were used to verify if the gesture does communicate the perception of a property of the fabric (e.g., communicates softness), using fabrics viewed digitally. *From looking at the person handling the fabric on the video, can you judge how the fabric feels?* Four gestures only were investigated to study if they would affect the ratings of "Smooth", "Hard", "Light" and "Rough". The gestures selected for analysis were: stroking, pressing, lifting and rubbing. The study showed that smooth ratings for the slow stroking gesture are always statistically higher than the smooth ratings for any other gesture. Hence, the slow stroking (caress) gesture did increase the ratings of a smooth fabric property. Hard ratings for the pressing gesture are always statistically higher than the hard ratings for any other gesture, except from rubbing.

Outside the textile realm, research showed that the haptic channel enhanced or enriched mediated communication and provided the capability to exchange contextual and nonverbal cues (Chang et al., 2002; Chang et al., 2001; Rovers & Essen, 2004; Rovers & Essen, 2005). By adding the touch channel, the amount of information transferred is increased (Chang et al., 2002; Chang et al., 2001). Studies investigating similarities between real and mediated social touch (Hertenstein et al., 2009) have used vibrotactile stimulation successfully, which indicate that this is suitable for touch-based activities (Huisman & Darriba Frederiks, 2013).

Considering both approaches reported above, tactile feedback generated by vibration motors were considered an appropriate means for simulating a touch gesture for perceiving textiles and, in order to bridge the gap between the digital and physical textiles, a Haptic Sleeve was designed to explore how the haptic feedback affected and/or altered the way people perceive textiles in mediated communication.

Device

This haptic device consists of two modules: an automatic module and an interactive module. The automatic module includes a haptic layer and a heating pad layer that provide haptic feedback and warmth respectively through computer control. The interactive module is the one that users can play with to explore more haptic patterns by themselves. The haptic sleeve is made of viscose fibre in-between a layer of sponge. It consists of two layers, one layer is a 3 by 2 grid of pancake style eccentric rotating mass (ERM) vibrotactile motors which is attached horizontally to the inner surface of the haptic sleeve using Velcro (Figure 2). The ERM vibrotactile motor used in this study is 10mm in diameter and 3.4mm in height. Every vibration motor was wrapped by kinesiology elastic tape and sewed to Velcro strips, which were in turn attached to the sleeve (Figure 2). It can generate different haptic feedback to render touch gestures presented in the video. The other layer consists of one DC powered electric heating pad and one temperature sensor (DS18B20), which can work as a temperature controlled heating pad to provide users with feelings of warmth. An Arduino UNO drives the ERM motors, heating pad, and temperature sensor.

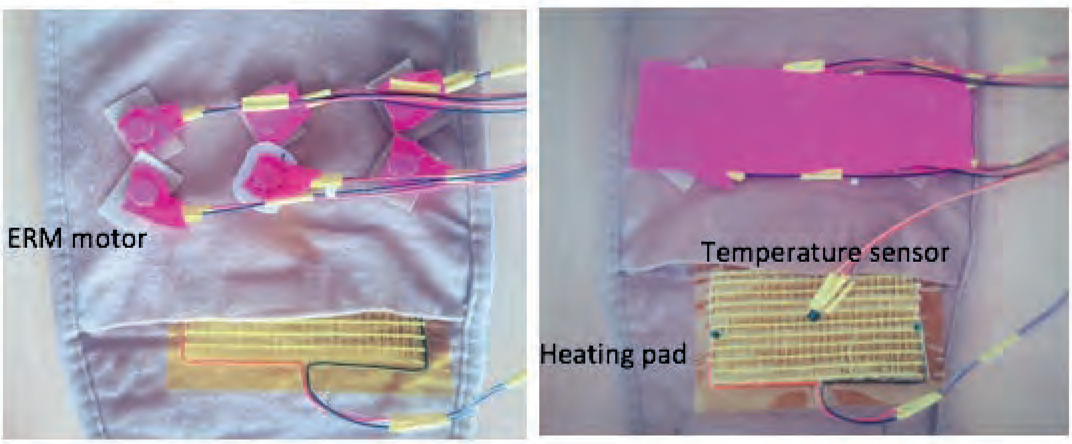

Fig 2. The haptic sleeve (including ERM motors, a heating pad and a temperature sensor)

In terms of touch behaviour patterns, people’s perception depends upon the frequency, amplitude, vibration and duration of each motor, overlap of vibration duration between subsequent motors (OSM), and the distance between two subsequent motors (Diehl et al., 2013; Oakley et al., 2006). Through controlling these five parameters, diverse haptic feedback can be formulated to render different feelings for people. For the feeling of warmth, a heating pad and a temperature sensor were used to provide a controlled temperature of 42°C for people to receive the sensation of warmth (Ciesielska-Wrobel and Van Langenhove, 2012).

To allow for interaction, a regulator that consists of three potential meters was used to adjust the value of three key parameters of ERM motors: intensity of vibration, vibration duration, and overlap of vibration duration between subsequent motors (OSM) (Figure 3a). Through manipulating three adjustable dials, participants can understand how different parameters could contribute to haptic feedback and the perception of fabrics (Figure 3b).

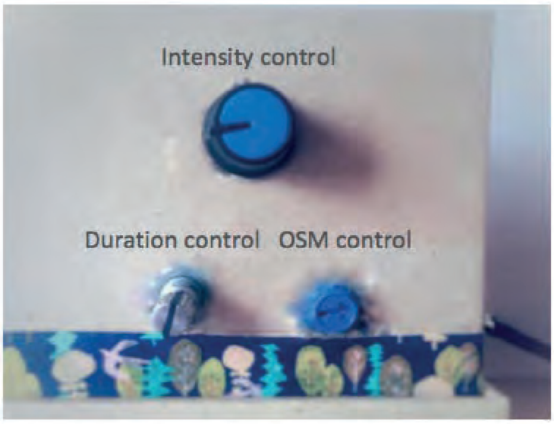

Fig 3a. 3 potentialmeters for interaction with Haptic Sleeve.

Fig 3b. Haptic Sleeve.

Fig 3. Devices for interaction with Haptic Sleeve.

Research on developing a touch language for experiencing fabrics demonstrated that touch gesture does communicate the perception of softness and smoothness of a fabric (Cary, 2013). This is not surprising as work on affective body expression had previously shown thorough an unsupervised approach (De Silva et al., 2005) and body feature analysis (Kleinsmith et al., 2005) that a subtle affective body language exists. However, this prototype enables us to better understand and design for these body experiences. This haptic sleeve enables to deliver haptic feedback that simulates these touch gestures generally used to touch textiles that were smooth, rough, soft or hard. This included haptic feedback simulating gentle caressing and rubbing. Participants wear the haptic sleeve that outputs various feedback types synchronised with the video clips showing someone interacting with a fabric (Figure 4).

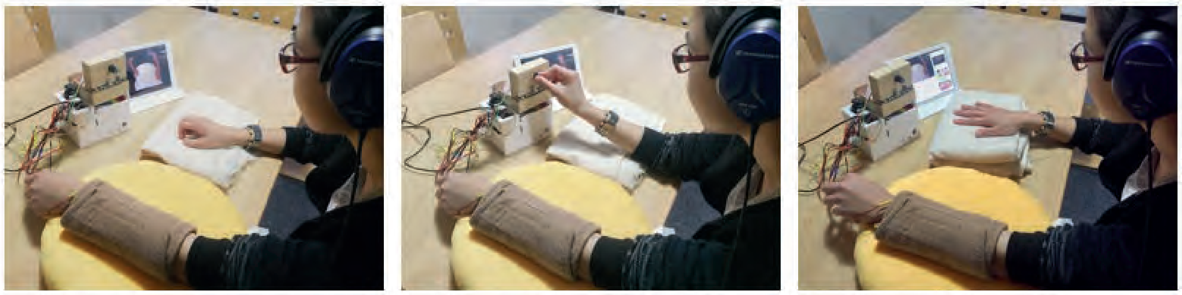

Fig 4. Participant interacting with the Haptic Sleeve.

Exploring different properties of textiles and experiences remotely

A majority of participants feel more connected to the textiles and enhances the activity of experiencing them. When participants were asked to interact with the haptic sleeve through three regulators and explore more haptic feedback (Figure 4), it was noted that this approach can help them better understand not only how the haptic feedback can contribute to the experience, but also how the textile and touching experience are related.

The interactions provided by the Haptic Sleeve allow enhancing the Simulate and Situate phases of the experience. The Simulate comes from the fact that one can change and try other parameters, which enables the exploration of different properties of textiles and experiences. The Situate is rather a co-Situate, as the Haptic Sleeve allows one to situate with someone else, as you try to share subjective experiences about the feeling of a textile. When interacting with the Haptic Sleeve, you are changing the parameters, or somebody else is moving the toddle, that is, Simulate on you someone else's feeling.

Here there is partially Situate and partially Simulate, as people could touch and feel what is happening on the other, or receive a caress adjusted by someone else, and we want to see how the body feels that. People explore it, and use different parameters. By changing the parameters, they were playing with different perception, through the different touch they would receive. It is interesting to see how other people Situate, so it could be a device for communication between designer and consumer.

The Hyper Textile

The context of this research was the advent of computational design and rapid prototyping as the body becomes a new support for innovation, and how fashion has been explored by engineering under the umbrella of wearable technology. Moreover, while many engineers are engaged in the development of wearable technology at high-level research, few fashion practitioners are involved. Fashion is a discipline that due to its proximity - and intimacy - to the body, can create knowledge to bridge object (dress) and subject (body), material (cloth) and immaterial (discourse). The current debate about the usage of digital technologies to mediate the design process brings an interesting discussion on new possibilities to rethink the role of the practitioner and embodied modes of practices. Building on previous research on the role of tactility in the design process, that revealed how complex touch behaviours are at both cognitive and subjective levels (Petreca et al., 2015), the Hyper Textile proposes to empower design practices that are relational and augmented. We argue that embodied knowledge and values can be transferred to digital by addressing a gap between traditional handcraft work with computational processes. The Hyper Textile resides in bonding different areas of endeavour, as a first attempt to propose a framework to create forms in which designers can actively engage with digitally aided processes rather than passively design through software and fabrics separately.

Device

The Hyper Textile was composed of three different fabrics cut in two meters each (Figure 5). The fabrics were connected to vibration sensors that captured when people touched the surface of the fabric and amplified the vibrations in real time, amplifying the original sound of each textile (Figure 6). Each fabric also played additional audio files, which was generated by vibration sensors connected to an Arduino board and controlled by a Pure Data command. There were three different audio files, which contained specific speech excerpts, each related to one of the three subdivisions of the research.

The design process was an attempt towards weaving design statements and practices together. Fabric selection, cutting and sewing weren't parallel practices to sound recording, code writing and cable arrangements. For this work the practice was expanded, it is augmented. The technological aspect gave support and enhancement to the other more crafty aspects of the installation. In the same way, the fabric properties - its touch, sound and feel - were equally essential to the technological functionality of the Hyper Textile.

Fig 5. Hyper Textile installation

Fig 6. Hyper Textile installation in use

Discover how you and the textile work together

This device enables an augmented exploratory experience through the relationship that both amplifies the senses and blurs the boundaries between the physical material and its digitally augmented properties, both the design practice and for the viewer. This augmented interaction creates a scenario for a more thorough and expansive material experience, which allow for possibilities that cross and go beyond its material properties.

The Hyper Textile is an enhanced representation of the interaction between a person and a textile sample. In this scenario, not only the sample is considerably larger, which encourages full-body interaction, but you also have an additional augmented sense which in this case the sound - something that is always there, but that is not so easily perceived. With that it enhances and augments Stimulation, which is facilitated by creating an extra channel of communication with textiles – not touch, or visual, but in this case sound, which makes the interaction much more vivid and inviting. Consequently, people go and really stay there and explore the textile. In participants' observation, we can notice them interacting more because the textile in movement "talks" to them; their interaction is sonified.

Here we select what to represent about the fabric, and about the body. This creates an engaging interaction with the fabric, and by inviting interaction it may lead to "Stimulating" experiences. In this case the sound was used, and that is just an example, but one could think of how that Stimulation phase can be enhanced by making the interaction with the body and textile, being enhanced through this representation, but using other channels. And also Stimulation can be empowered by the fact that you engage more, and discover more.

Discussion

Throughout our research we have developed diverse tools and methods to investigate and support designers in experiencing (Petreca et al., 2016; Atkinson et al., 2016; Yu, 2016; Saito, 2015) and selecting textiles (Petreca et al., 2015; Petreca, 2016). In this process we have realised the importance of developing our own means to engage with this experience, in order to aid designers in focus, elaboration, articulation, and communication of the experiences they have through and with textiles. We have done this using mainly two types of strategies, which are about focusing (on the body part, on the characteristic of fabric you've decided at that moment, on the textile interaction, and/or on who is generating) and representing sensation. These are summarised in Table 1.

Table 1. Diverse tools to support embodied design processes.

<table>
<tr><th colspan="2">STRATEGIES</th><th>POCKET-TOOL</th><th>HAPTIC SLEEVE</th><th>HYPER TEXTILE</th></tr>
<tr><td rowspan="3">Focus</td><td>Body part</td><td>Fingers</td><td>Arm</td><td>Full-body</td></tr>
<tr><td>Textile interaction</td><td>Physical properties (e.g. Thick – Thin, Stiff – Flexible, Warm – Cool, Rough – Smooth)</td><td>Physical properties and textile-based concepts (related to design application)</td><td>Meaning-related characteristics (metaphors, associations, etc.)</td></tr>
<tr><td>Person generating</td><td>Oneself</td><td>Oneself or another person</td><td>Oneself</td></tr>
<tr><td colspan="2">Representation</td><td>Visual</td><td>Tactile</td><td>Auditory</td></tr>
</table>

As can be seen from Table 1, by testing how technology can empower embodied processes, we have completed the initial framework proposed, based on the 3 tactile-based phases Situate, Simulate and Stimulate. Reflecting back at these proposed tools, we realise that these strategies also led to particular ways in which we have structured our approach, and which could be taken forward as themes to be further explored for the development of other tools.

The devices presented in this paper demonstrated three main routes to focus on the embodied experience:

Immersion in experience - by developing and delivering the means (tool or method) for designers to have an immersion in their own touch experience of a textile. The effect noticed was that when designers have the agency to navigate their experience, they will focus their attention on aspects that emerge as relevant during its course;

Mediating the experience - since in our current context touch experiences with textiles are sometimes lacking, for example in digital design or online shopping, and by receiving a mediated touch (in this case through a haptic sleeve), participants feel more connected to the textiles and their experience is enhanced;

Augmenting the experience - by purposely focusing on certain qualities of an experience that are heightened to provoke and evoke reactions, and the effects observed are of a more playful interaction, that keeps the designers actively exploring and engaged in the experience of involving the whole body in such explorations.

These three approaches - immerse, mediate and augment - show possible and fruitful paths to further our understanding of the embodied experience with textiles, through investigations on touch interactions. As we are progressively entering spaces where our processes and products will increasingly inhabit blended spaces, between physical and digital, if we are willing to create more alive, active and adaptive materials, we believe further exploring the roadmaps we have proposed through this paper will have a disruptive impact on the design field - of designing with our materials, with our whole bodies and contexts engaged.

Building on the framework described above, we can open up the discussion to propose some following concrete applications that may benefit from the findings from the three projects presented:

1.Design Education and Practice: There is an underexplored potency in this approach, that is to promote an *"ecology of knowledge"* (Santos, 2007) in design research and practice. This would lead to a recognition of an epistemological diversity of knowledge and its actors within design, in particular to the theme of this paper, the validation of tacit knowledge as opposed to hard sciences only. Within this mindset, here there is an opportunity for development of tools to support designers or design teams - local extension, for personal use or sharing - that facilitates processes of articulation and communication on a tacit basis, i.e. relying on the designer subjective experience and experiential knowledge.

2.Co-Design: The devices described in this paper deal with both personal and shared material experiences, as well as the use of data representation and collection as non-verbal relational tools. Such affordances can support co-creation practices, as they might benefit from new possibilities for remote communication between multiple stakeholders.

3.Commercial/Industrial Settings: Radically relational approaches to design offers opportunities to explore commercial contexts within online and offline environments (local or remote). It is safe to affirm that when both environments are explored in a hybrid manner, this can lead to more seamless user experiences. We could easily see this working in consumer customisation settings, with services that combine in-store and/or online experiences.

Moreover, our research challenges current understanding of design practice, as these tools open up paths for investigations within a hybrid, interdisciplinary approach, which inhabits both physical and digital spaces. Finally, despite the emergence of tools that can directly capture how a person feels about textile (Singh et al., 2014), we argue that technologically aided material engagement and exploration can lead to exciting new radically relational developments in the ways we think and do design. In future work, we hope to further stretch the use of technology to explore material interactions with the support of augmented reality, virtual reality and haptic technologies.

Acknowledgements

Though the work reported is the result of a collaborate effort to bring three distinct projects together, we recognise the need to address author's contributions separately.

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Air, Metonymy/Mimetics: Making Form, Playing Form, Form in Motion

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Abstract

Form and form-making are central to every (object-based) craft practice, therefore the impact of emerging technologies on craft processes which involve software as an approach to form-giving becomes significant in the thinking, making and fabrication of objects. This study investigates the role of digital forming of air as an interactive method in form-finding in ceramic craft. It focuses on the possibilities of generating three-dimensional digital models by using 3D Scanning/Imaging and the 'Sense' programme by way of cultivating an integrated digital approach to ceramic craft making. The adoption of software into ceramic crafting involves the assimilation of digital-making into the physicality of hand-making through metonymy/mimetics. The project, developed at the Fab Lab Made@EU, Plymouth (1), attempted to integrate the hand-made and digital technology and stipulated that the making of ceramic form could be embodied in the act of shaping air as a flexible material.

Keywords:
digital crafting, materiality, digital forming, ceramic craft, fabrication, metonymy / mimetic

Introduction

This practice-based project investigated the possibility of crafting form by using three-dimensional Scanning/Imaging and 'Sense' software by way of assimilating hand-making into digital technology. The project, developed at the Fab Lab Made@EU Plymouth (2) intended to advance an alternative making technique in ceramics and aimed to test if form could be embodied in the physicality of the act of shaping *air* as a material through *mimetics*/*metonymy*.

With the adoption of new technologies, the *traditional* and the *new* come together and craft is no longer limited to the notion of the hand-made: 'Neo-craft', 'Crafticulation', 'Interaction design', etc. propose new craft/digital hybrids, suggesting technical overlaps between the hand-and-digitally made. The profusion and diversity of software programmes and digitally-driven making processes, defining precise digital crafting methods of visualisation and production - like clay extrusion, 3D-scanning, 3D-printing or CNC patterning, stereo-litography; CAD animation and CNC milling; video or motion capture technologies, digital mapping, additive layer manufacturing; rapid prototyping, laser-etching, etc.) - expand the praxis of craft. However, the new developments in digital craft are those which overlap or disrupt the set rules in such programmes to test new possibilities of practicing craft. In this view, rather than following a particular digital craft practice, this project attempted to combine two technology-based processes – rather than following their set, conventional use. It adapted a programme commonly used for capturing still-images (3D scanner) and converted the process of image-making into motion in order to visualise form-making. As digital approaches follow an ordered protocol controlled by precise algorithms and function on simulation as a basis for conception and production, this project's approach was based on the concept of **metonymy and mimetics: imitative, simulated, derivative** and as such was concerned with the dematerialisation of making.

Digital and Craft Contexts

The use of computers as 'rapid prototyping' tools for industry at the time when 'New Craft' and 'Studio Craft' practices emerged in Western culture in the1960s, and their distribution in the 1980s and 1990s altered the role of craft-skill and craft-making. Such shifts reflected a culture of production which interchanged hand-made, computational and industrial production methods. In adopting digital technologies, craft-based disciplines adopt integrated approaches regarding form-generation – changing from process-related to coded-related making approaches and opening up the concept of practicing craft.
The introduction of software into all crafts has developed rapidly over the years, contributing innovative ideas to a diverse history: exhibitions like Lab Craft (2010) or Power of Making (2011); conferences like 'Make: Shift' (2014) and events like 'Make: Shift: Do' (2014) 'Challenging Craft', 'New Craft Future Voices' (2007), 'Neo-Craft' and 'Crafticulation' (3). These events, reflecting the effect of technological revolutions on craft, demonstrate the potential of digital fabrication and the innovative use of digital tools in blurring creative boundaries and permeating hybrid making practices. The approaches presented in these events surpass practice of craft – they define craft practice as design.
Contemporary makers, designers and architects now combine material and immaterial types of production: Marc Forness (*Aperiodic Vertebrae*) developed a computational prototype made of 360 elements to create a variety of forms and structures; Greg Lynn (*Flatware*, 2005) designs utensils by mutating basic forms; Front Design developed *Sketch Furniture* (2004) by freehand sketching and recording lines with motion-capture video technology; Crescent, Japan (2006) translates drawings into digitised 3D computer models; Neri Oxman (*Soundwave*) and Batsheba Grossmann (*Tuskshell Biomorphic Design*); Myrto Karanika and Ghislaine Boddington combine software with body responsive technologies and traditional craft to create immersive experiences and interactive interfaces. New programmes such as 'Digital Anarky' initiated by Ann Marie Shillito investigate haptic-based models of 3D modelling software (virtual 3D touch) making possible the representation of human interactions with materials as visual constructs (5).

In blending the virtual and the physical, such initiatives attempt to translate, re-capture or reproduce, the materiality of craft-making, and 'Increasingly, tangible interaction design is orienting itself towards craft as something distinct from design'. (Kettley, 2005) What is important to signal here is that these innovative approaches transfer the creative input from the maker to the digital, and in the process lose the close interaction of the body in begetting form: an aspect which remains essential in the practice of ceramics. On the contrary, in devising an ideal concept (form) the digital aims for – as Sarah Kettley (2005) observed - a purity 'untainted by worldly bodies or material, and the artlessness of spontaneous expression'. In this view, my experimental approach aimed to test the possibility of shaping objects by starting the forming process outside the computer screen, as a hand-making, a mimetic model of modelling - therefore not commencing with programmed data.

Air-forming: the mimetics of the hand-made (relocating the hand-made), making and material

In this technology-led context of change in the praxis of craft the tradition of hand-making becomes replaceable, and the performance of the maker translated into a digital semantics. My project aimed to parallel a craft-based, physical processes of forming clay (material) within a digital medium - virtual (immaterial). In this view, it attempted a dematerialisation of hand-making, followed by a 'materialization of digital information' (Ratto and Ree, 2012).
Although as product and as process craft has moved from being defined as hand-skill, the tacit knowledge of forming remains valuable: in 'Abstracting Craft' McCollough emphasized the physicality of making: 'Hands feel. They probe. They practice. (…) The knowledge is not only physical but experiential' (p.8) – and as such eludes the scientific, logical description specific to a digital process. Therefore, materials, materiality, and forming matter are central to craft. In the case of ceramics, materiality is fundamental to form-making, hence a digital approach is a problematic engagement. Unlike clay, air is an everyday substance readily available and is experienced daily in many forms: hot air, polluted air, closed air, cool air, bad air, sweet or fresh air, air-conditioned – terms that refer to specific perceptions of smell, humidity or temperature. Although is inhaled in and out more than 20,000 times a day is too transient, too evanescent a substance to be captured; yet it contributes, for instance to our experience of a building, in creating place through a fragrance, it enables the perception of light and it carrying radio-waves; it has been captured and shaped in inflatables. While is formless, it can be shaped.

Forming air rather than clay provides an opening of material boundaries: clay has structural and chemical limits, resistance, stability, air does not. There is no opposition from air, no restriction to what can be shaped. In traditional clay-forming the body of the maker is at one with the material in a responsive, immediate, reciprocal interaction. In this 'photographic' approach the interaction with air is reflected in the scanning of image – it is the echo of the corporeal movement. As such, the experience of forming without a material relays on the three-dimensional bodily movement, the tactile-like, sensory experience of hand-making. (Fig. 1a/b/c/d) As the materiality of clay is missing, the forming process is enabled by the bodily memory of shaping clay through a copying and reiteration of modelling movements – a photographic embodiment of these – a mymesis. As forming in ceramics is bound to a lexicon of movement, shaping the air is an approximation (a mimetics, corporeal as forming air in a mirrored image) of such movements. Forming air is an imagining of form in the fluid, narrative movement of hands – a simulation, a Thai-Chi reshaping on-screen. Treadway (2009) refers to 'concept generation' related to' memory and lived experience' and a 'conceptual blending' that is 'experienced and perceived, remembered and imagined'. Through the hand-and-air movement, form mutates into image and translated in code into a digitally-controlled fabrication.

The digital tracing of the form-making movements, performed 'in the air' were recorded live by a three-dimensional Scanner visualising motion, and translated into on-screen forms. (Fig. 2 a/b and 3a/b). In 'Sense' the screen becomes a performative space where form-giving is a mutable process of form-tracing and form-finding. The visualisation of forming the air becomes a visual communication that defines form possibilities, a play with a variety of digital scenarios of form. In this exploration form is released in a series of conversions - from surface to solid, from ambiguity to object, from movement to a digital casting. (Figure 4 a/b/c/d and 5 a/b) In this process, form is transferred into on-screen models of ‘negative’ space to be relocated into craft techniques and related back to materiality as 3-dimensional solid objects ‘digital’ prototypes.

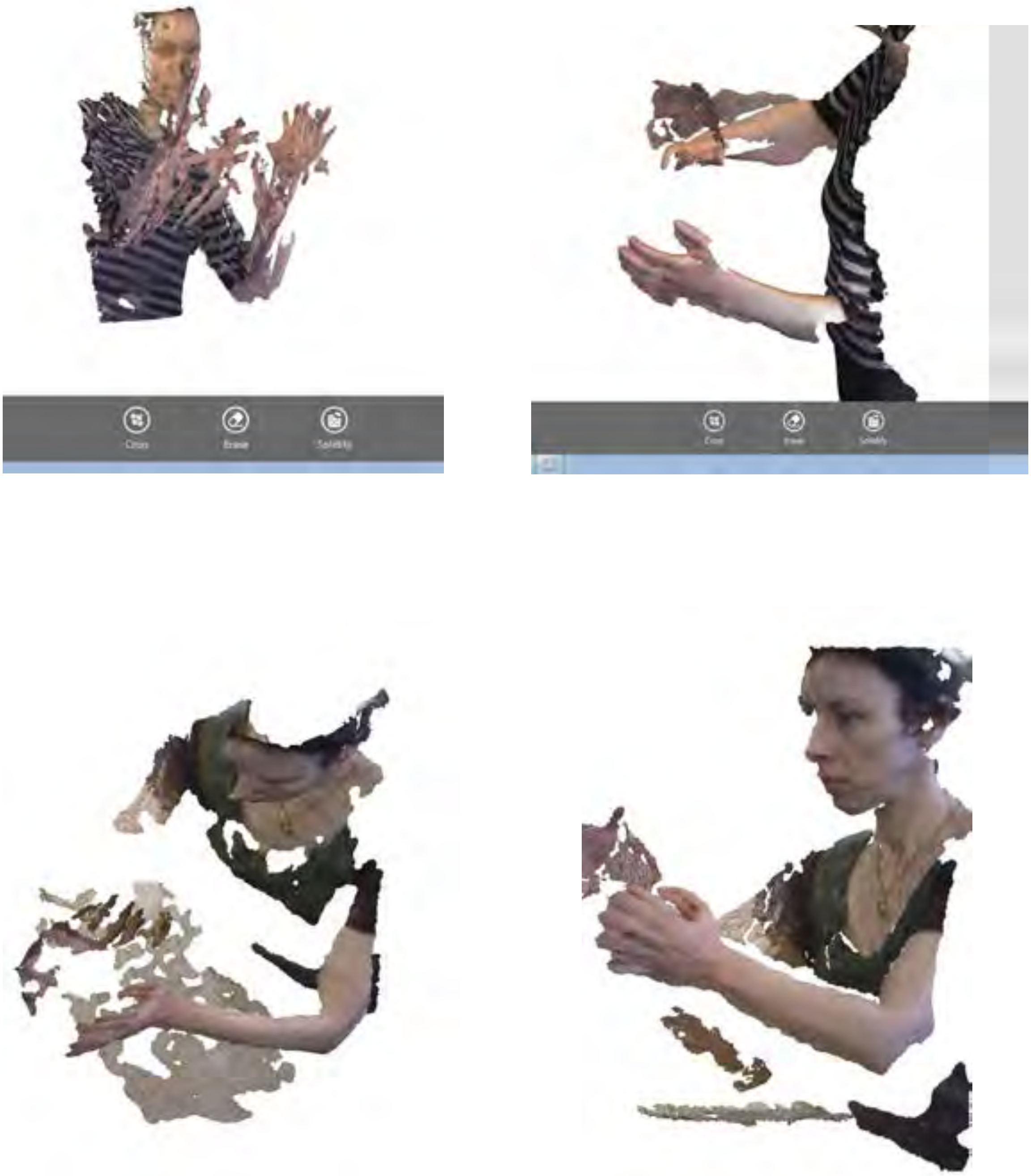

Figure 1a/b/c/d. Forming the air, 3D Scanning. A. Ionascu (2016)

Figure 2a/b. Solidifying the air, 3D Scanning and transfer into Sense. A. Ionascu (2016)

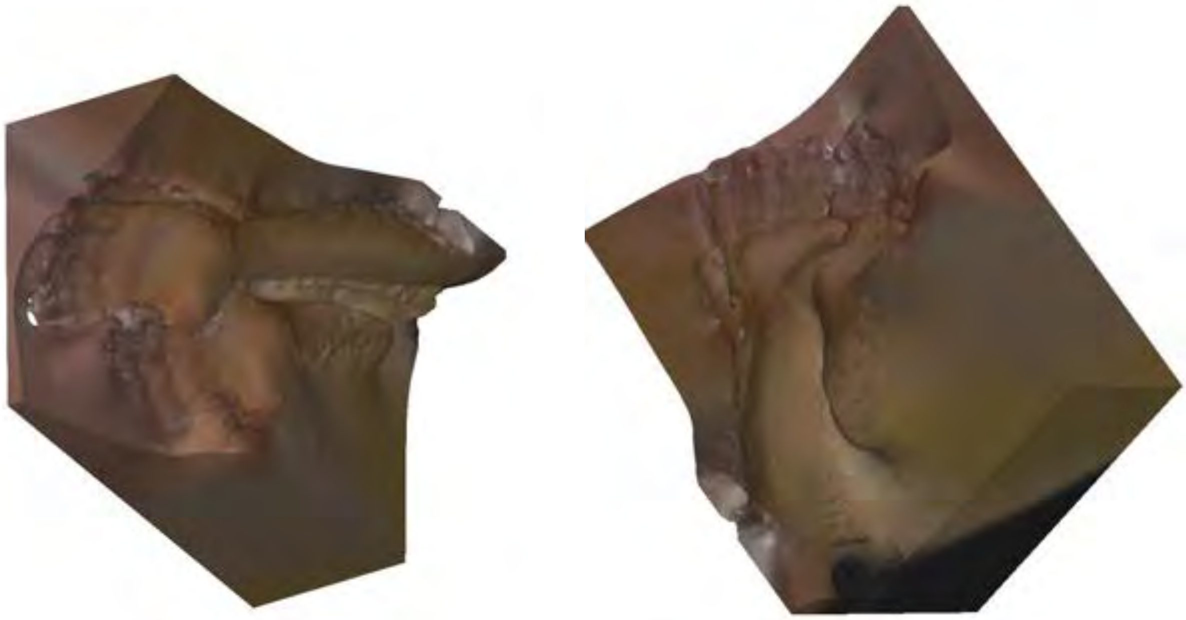

Figure 3 a/b. Shaped Forms translated in ‘Sense’ programme. A. Ionascu (2016).

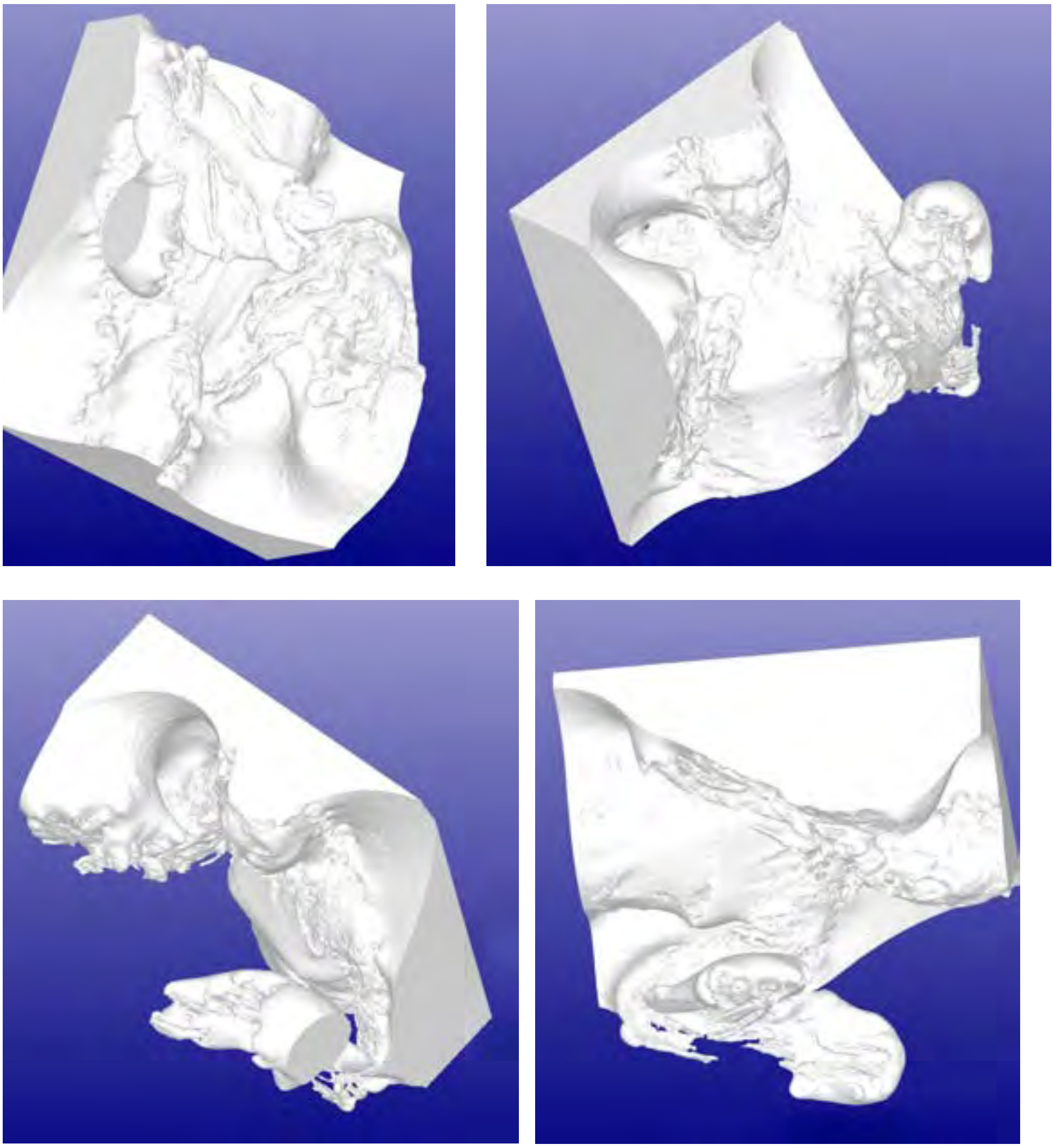

Figure 4 a/b/c/d. Forms in ‘Sense’ programme ready for production. A. Ionascu (2016)

Figure 5 a/b. Forms in ‘Sense’ programme. A. Ionascu (2016)

In conclusion, the 'somatic experience' of hand-making translated through a physical mimetics of shaping *air* as a flexible material was an intuitive process of appropriation. In this sense, the approach considers making as a process informed by the bodily sensory experience of remembered movement. In the context of 'studio craft', the project created an experiential space and questioned the role of tacit experience of the body. Accordingly, three-dimensional scanning and the 'Sense' programme were chosen as connected methods of mirroring, of photographic reiteration of movement. By tracing the movement of shaping the air into form, the software enabled the iteration, the duplication of form without materiality. Besides being useful in visualizing as a digital transcript and thus reconsidering concepts of form, 'Sense' software made possible the recording and decoding of form (through its connection to a printing machine) into material (as if a painting becomes 3-dimensional).

Critical Reflection

This project endeavoured to integrate digital-and-craft processes of making as a way of expanding the possibility of generating three-dimensional form in ceramic practice. It aimed to align with other models of digital fabrication in contemporary craft reconsidering the role of form-making in studio ceramics. Malcolm McCullough (Abstracting Craft, 1998) argued that the medium of computation enables a valid correspondence between digital and hand-craft, in spite of limitations of human-computer interaction and abstract methods of production related to design. However, it is relevant to observe that in many digitally-led current maker practices craft is defined and practiced as design. Form-making, in many of these cases (e.g. 3D-printing, CNC patterning, stereo-litography; CAD animation, digital mapping, additive layer manufacturing; rapid prototyping), starts 'inside' the computer, being defined by specialist programmes; whilst this project attempted the construction of form outside the computer screen.
In testing the role of digital craftsmanship as an approach to making, this experiment raises questions regarding the craft of making: to what extent could the sensory know-how of moulding form can be transmuted into a digital format? How the 3D-imaging and on-screen impressions of modelling translate the physicality of making? How form can be developed on-screen in ceramics practice?

Clearly, the intersection and exchange between craft and digital processes and methods of making, enable a digitally-mediated craft practice which informs new processes and applications.

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Notes
(1) PCA Made@EU' FabLab, IAAC Barcelona, ENSCI Paris
(2) PCA Made@EU' FabLab, IAAC Barcelona, ENSCI Paris
(3) The first Make:Shift:Do programme took place from 21 to 22 November 2014, in partnership with the V&A, Institute of Making and the RSA.
(4) Anarkik 3D Design uses a Haptic Device which is essentially a 3D mouse that provides 3-D 'touch' and 'feel', an interactive resistance known as force feedback. This approach enables the sensation of touch and movement in 3-dimensions (across the x, y, and z axes)
(5) *Challenging Craft* comprised of a three-day conference hosted by Gray's School of Art, The Robert Gordon University, Aberdeen

Biography

Dr Adriana Ionascu studied Fine Art in Europe (Jassy) and Design at Loughborough University School of Art and Design. Her Ph.D. thesis (*Poetic design*) focuses on the cultural significance of domestic artefacts. Her research focuses on DesignArt, Critical Design, especially the social role of design in modelling experiences of modern life; and design as a network of events, objects and histories.
She contributed articles to journals such as *Ceramics: Arts and Perception* (2007), guest-edited for *Visual Inquiry* (2013) and is principal editor for *Drawing: Research Theory Practice* international journal (Intellect). She presented papers to Design History Society International Conferences at Koniklijke Vlaamse Academie Brussels (2010); to Oslo School of Architecture and Design (2009), Delft University of Technology (*Design and Evolution*, 2006), Chalmers University Gothenburg (*Design and Emotion*, 2006); Amsterdam School of Cultural Analysis (*Engaging Objects*, 2008); to *Making Futures* International Conference, Plymouth (2009-2016), *New Craft, Future Voices* International Conference, Scotland (2007). She exhibits in England,

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An experimental approach for the inclusion of the experiential aspects of lighting through the design process of atmospheric luminaires

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Abstract

This paper, based on the capacity of light to form the material area around it, seeks to understand the possibilities towards the implementation of light in design, as an empirical phenomenon. Aiming to extend the concept of atmospheric luminaires and to support their design, a design framework in the form of design tool format is proposed.

By understanding the experiential nature of a luminous atmosphere, it becomes clear that its interpretation is personal and subjective and thus the design approach should not be seen as problem solving but as an opportunity for creation and experimentation. The design approach is proposed, address the stages of inspiration, ideation and experimentation, which are based on one of a craft-based logic, which characterizes the research process of assessment. In conclusion, each stage is described in order to support designers to create atmospheric luminaires which embody the designer’s effort to transform a luminous atmosphere into user experience. According to that, the basic features proposed for the design of atmospheric luminaires, are: the dual nature (material and immaterial), Dynamic form and affect, Active user participation, Immersive user experience, Tangibility, High levels of empathy, Transparency (in the context of use and creation methods).

Keywords

Atmosphere; Craft; Luminaire; Phenomenology; Perception

This study explores the experiential aspects of luminous atmospheres and investigates ways to design artifacts that contribute to their creation. The challenge of this interdisciplinary design research is that, even though technical and quantitative parameters can describe light to some degree, they fail to capture the essence of the phenomenon and explain the different perceptual phenomena (Celi, 2010) that arise when experiencing a luminous atmosphere.

The motivation behind this research is the exploration of the engagement with illuminated materialities that tune the senses, trigger emotional mechanisms and create a field suitable for meaningful interaction (Ebbensgaard, 2015). With the suitable approach, designers could utilize these qualities in order to create design concepts that foster immersive experiences. In this paper, we put forward the idea of a design framework that, through a craft-based approach, supports the design of atmospheric luminaires while managing to embrace the notion of subjectivity that defines the experience of a luminous atmosphere. The study continues with a research through design approach, in order to gain insights through the actual creation of atmospheric luminaires. Luminous atmospheres are an immaterial phenomenon but at the same time designing them has a lot in common with craft and ‘material driven design’ (Karana, 2015), with the light playing the role of the material.

The framework required for the design of these types of atmospheric luminaires is rooted in human centered design approaches that take the design for emotion and advanced lighting design into account within a phenomenological perspective. The goal of this process is not the creation of a technically sound artifact that pragmatically address all the necessary dimensions of light. The goal is the creation of experiences by interacting with the user. In order to better utilize the conclusions, we drew through the literature research and transform the outcomes into characteristics that the artifacts designed have to possess.

The proposed design tool aims to enable the design of atmospheric luminaires and the surrounding atmosphere. The target group of this tool is made up of:

- Product designers and craftspeople working with light
- Researchers aiming to create new empirical and tacit knowledge in the context of lighting design
- Artist looking to express themselves and experiment using light as a medium

Materiality of luminous atmospheres

Light due to its immaterial nature can be viewed as an experiential phenomenon but the way it is experienced is tacit, it cannot be reproduced or fully explained. Despite light's immateriality, light is what enables the experience of materialities in space. It permits us to perceive the surrounding environment making it a medium through which our perception of space and its surroundings becomes possible (Ebbensgaard, 2015; Ingold, 2005). The ephemeral and intangible qualities of light can reveal texture, accent and spatial transition (Edensor, 2015) and at a level of abstraction, both light and space can transformed into materials as volumes, surfaces and colors. Color and light are entwined, in a similar way the material and the immaterial cannot be separated (Weibel, 2006). It is this intermediate status of light that describes its materiality, similar to its very nature being a wave of energy and a stream of particles.

This intermediate status is in line with the concept of 'materialized energy', an idea Bohme introduced under the notion of 'atmospheres' and proposed it as a fundamental concept of a new aesthetics (Böhme, 1993; Löschke, 2011). The objects within a space and their manipulations, could create the suitable conditions for an atmosphere to arise, but without the subject, an individual to experience it, an atmosphere could not exist (Böhme, 2013). So, based on Bohme's statements about atmospheres, the notion of atmospheric lighting in this current study is developed by taking into account atmosphere's peculiar intermediary status between subject and object that depends on the space, the objects and subjects within it and finally evolves from their interactions (Böhme, 1993; Schmitz, 1964).

Light plays an important role here, because of its performative function to transform the way people experience space. The illumination of specific objects creates narratives between them and combined with different types of luminance, or lack of thereof, express a dynamic form of space (Ebbensgaard, 2015). McLuhan states that "it is the medium that shapes and controls the scale and form of human association and action" (McLuhan, 2011), and this is why not only light's capacity to reveal the environment that should be taken into account but also its capacity to create symbolic associations and meanings that alters the subject's final perception of the environment (Gertz, 2010; Edensor, 2015).

Artists of the contemporary art movement 'Light Art' use light to "sculpt the spatial perceptions of viewers" (Katzberg, 2009) aiming to get the viewer embodied within these art installations. The art space is full of practical knowledge concerning atmospheres and their creation but when it comes to the integration of that knowledge in the context of a wider aesthetic theory, it becomes apparent that most design decisions are based on knowledge that is either implicit or tacit (Böhme, 1993).

The visual aspects of the experience are important in shaping an atmosphere but they don't stand alone, they have to exist in combination with a range of other sensory, subjective and narrative elements (Edensor & Sumartojo, 2015). Each atmosphere is composed out of multiple phenomenological and sensorial elements, rooted in personal memory and subjective experiences (Edensor & Sumartojo, 2015) and inspires different interpretations (Ebbensgaard, 2015). The subjects through their reactions and interpretations, act as co-creators of the atmosphere and, by extension, the environment (Edensor, 2015).

Research methodology: A craft approach for an immaterial medium

The logic of craft is conductive to the overall understanding of the notion of luminous atmosphere and at the same time, it provides the tools to integrate the empirical and experiential nature of lighting phenomena in the design process. Approaching the design project with respect to the embodied experience of an immaterial atmosphere and the subjectivity that defines the stages of evaluation of the user experience, an understanding of tacit practical ways of designing associated with craft is required. Additionally, the embodied character of atmospheres cannot be analysed separately from the cognitive aspects of it, which come in line with craft practices, where making and thinking are inseparable (Nimkulrat, 2012).

All of the above, point to the fact that trying to understand these phenomena based solely on systematic research, literature review and objective knowledge would prove to be a fruitless endeavour. Deleuze claims that the difficulty associated with the lack of concrete scientific knowledge has to be addressed with ingenuity as a possibility for creation (Colebrook, 2001). Hence, the methods to design atmospheres should contain notions and practices open to improvisation, interactivity, experimentation and controversy. (Edensor & Sumartojo, 2015).

Such a design methodology needs to integrate the self-referential study of itself in order to construct design approaches and design tools (Cross, 2001). Schön put forward the idea of the ‘practitioner researcher’ (1984) who, by engaging in ‘reflection in action’, studies the process of creation while engaged in it. The implicit decisions, strategies and theories converge towards creating habits and finally a behavioral motif (Nimkulrat, 2012; Schön, 1984). This phenomenologically based approach is rooted in personal knowledge and subjectivity, based around perspective and sense making (Lester, 1999).

The phenomenological research paradigm refers to an attempt to understand the substance of a phenomenon by approaching and analyzing the way in which it is experienced by the individual (Lester, 1999). This form of research not only addresses the notion of atmospheres but also supports their design. In this particular case, the phenomenon studied is the decision-making process during the design of atmospheric luminaires with emphasis on the role that intuition plays in this process. In its core this analysis is a process of self-reflection around the thoughts and actions of the practitioner researcher. The goal is to uncover how personal experiences, capabilities and also engaging with physical materials guide the process of designing an atmospheric luminaire. In this context the focus is not the artifact but the process that brings said artifact into this world.

To achieve this goals, different design processes will be undertaken and reflected upon in an iterative manner. The results of this reflection will be seen in relation to the literature review conclusions and integrated in the next iteration of design praxis. The end goal of this process is the development of a rigid framework for the design of atmospheric luminaires that will describe the core characteristics of said artifacts and ways to achieve said characteristics.

The basis of this approach exist in preexisting design methodologies, so a secondary goal of this study is to select and combine the necessary cognitive modules that fit within the overall framework. Overall the three stages of this research through design are:

1. First design experimentation
2. Reconceptualization of Atmospheric Luminaires
3. Design Approach
4. Reflection on the Design Approach through a second design experimentation

First design experimentation

This first attempt to create an atmospheric luminaire took place before the composition of a rigid design framework. This experimentation is an attempt to reflect on the outcomes of the knowledge, gained during the theoretical part of this study, through a practical procedure. The goal of this procedure is not the creation of a technically precise artifact, but to get a deeper understanding of the context of inquiry through the intuitive decisions happened within the design process.

Usually the first step of the design process is brainstorming. Later the designer, or the design team evaluate the ideas generated depending on the current design goals or the selected target group. In this design case, due to the fact that personal bias shape how a luminous atmosphere is experienced, the evaluation of the ideas was not undertaken, as it is impossible to predict all different interpretations. So, in order to find a starting point, the designer-researcher would not try to present every possible idea and then to evaluate the most suitable, but try to analyze the first idea comes in mind and find the roots of this idea depending his/her own personal memory.

The first idea is to design an artifact that has the ability to project colored light and enables the user to change lighting effects through some readymade slides with different colors or patterns. Things like novelty, originality or functionality of this concept are not a prerequisite. The basic focus is to ask why this idea came up. In order to ask this question, an internal critical dialogue is been made and presented to the following mind map.

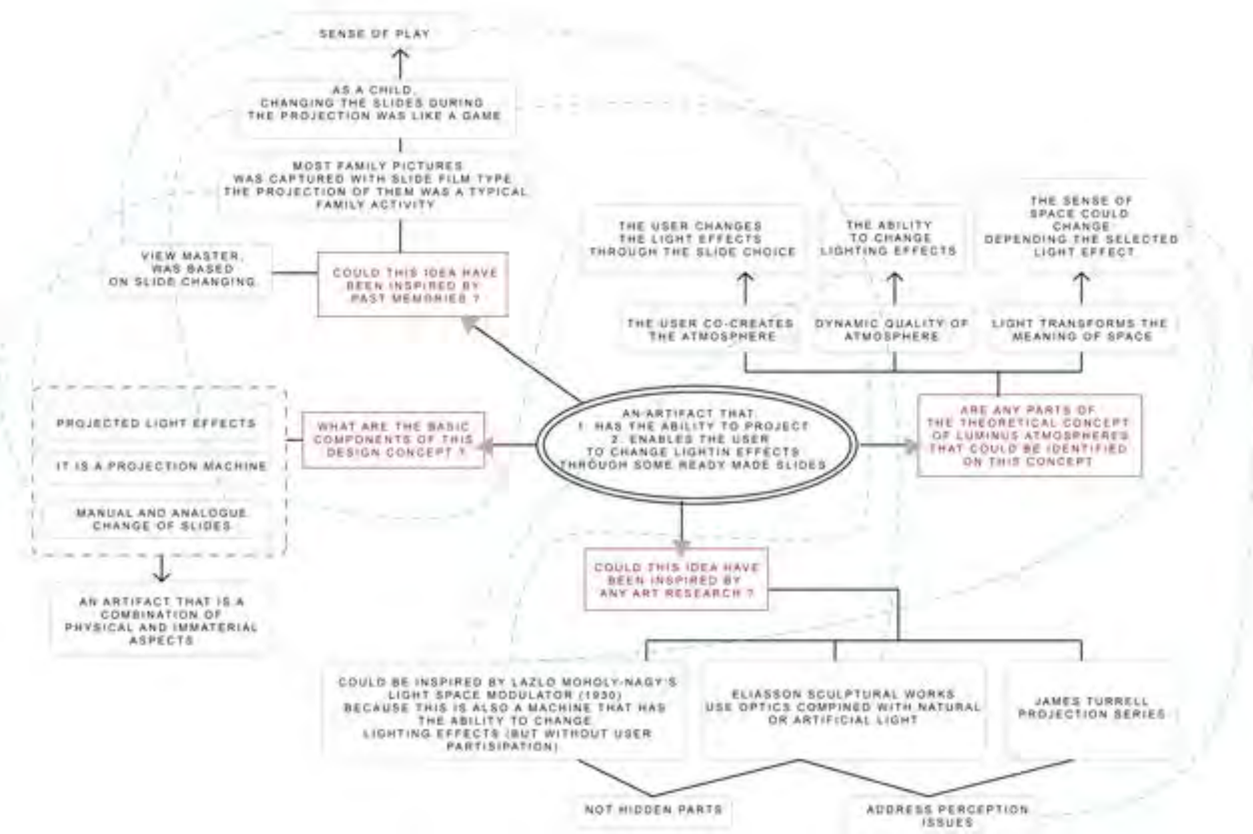

Fig 1. Projector's Mind Map: A mind map that shows the roots of the concept idea of first experimentation.

This reflective mind-map shows how theoretical knowledge and past memories are interconnected and how they intuitively led into design decisions. Every question seems to have an answer and helps to unlock deeper reflective conclusions.

A design goal that came forward was 'to achieve active engagement of the user in the creation of luminous atmospheres'. This goal enables the artifact to act as a conduit through with the user understand his role in the co-creation of the atmosphere. This core idea of the artifact is also the implicit need of the craftsperson to address co-creation in practice, in relation to the phenomenological approach based in cognitive meaning making.

The following table shows the steps of the creative process, the materials used and the reflection of each stage.

	Cardboard Model	Sketching	Ceramic Model
Pictures			
Goals	• Explore and understand the structure of a projector	• Experiment with acrylic sheets • Define rigg • Static Study • Integrating the light source	• Explore the structure of the periscope projector • Explore how the lighting effects compined with the designed form of projector's body.
Materials	Cardboard, 5x zoom lens, small flash light Pink transparent pvc for the slides		Clay,5x zoom lens, small flash light Pink transparent pvc for slides, one photo slide
Projection Tests			
Reflection	• During the projection tests, there was the belief that the projected colors has an intrest-ing affect on the enviroment. With a second look, the lighting effects was not what make the enviroment intresting but the fact that these effects are the first optical result of the whole creative proccess, from the theoritical research till the model construction	• The material choice (clay) seems to affect the form even during the sketching phase. This curvy form could easily conctructed with clay.	• This model reveals researcher's lack of sufficient knowledge (opticts) in an experiential way and helps for further and more specific research. •The cunstruction of the model led to high levels of possitive affect, because of the nature of clay. •Accidentaly broken parts gave intresting lighting effects • Once again, the intresting part was the experimental projection process and not the projected effect itself
Negative facts	• The fact that this model is lo-fi and created with temporary materials does not inspire the researcher to experiment with more projection tests, even though this could be usefull	• The fact that light effects could not approached by sketch, this phase focus on functional parts that are not essential for this research through design study.	• When clay dryed, the parts that was designed to help the slide changing broke. As a result, the interactive part of the slide changing was difficult.

Fig 2. The creation process happened during first experimentation

Reflection on first design experimentation

The experimentation begins with the idea of the projector, an idea that explains what has to be designed, but not why. Mind mapping and reflection of the creation process helped to understand and set the goals of this design concept.

The concept of the view master can be considered outdated if we consider the high-tech definition of digital projectors with amazing capabilities. However, during the experimentation, what came up was that the fidelity of the projected image was not important. The way the user affected the luminous results enables the immersion in the atmosphere as well as its co-creation. This is also evident in the mind map, that uncovers that the physical interactions during the immersion process give a game-like character. This character fosters the experiential nature of light, as it simulates the materiality and natural feel of light during the interaction. At the same time, the choice to focus on the projection procedure rather than the end projected result was intuitively inspired by the research through design methodology itself, where the end goal of the process is not to create a finished artifact but to study and understand the process.

The mind mapping method enabled us to understand a purely personal experience and to translate these insights to more general conclusions. The subjective and nostalgic idea of adjusting the projector was analyzed and broken down to elements that can be translated into design goals. The goals are centered around the overall character of the interaction with the artifact and do not address the final interpretation that the user attributes to the atmosphere created.

Fig 3.Details of the ceramic model. Inside there is a mirror that enables light's reflection.

When it comes to the design of lighting effects, ideation through sketching appears to be insufficient. Although sketching helped with formalistic approach of the artifact, there was a clear need of a physical prototype in order to test the projection effects. The combination of sketching and prototyping enabled us to better organize the whole process of actually creating the artifact. At the same time, the mistakes that happened during the process enabled the evolution of the atmospheric luminaire. This supports the idea of early stage prototypes and their evaluation during the ideation phase. Even though the ceramic prototype can be considered more evolved that earlier paper prototypes, we still address them both as early stage prototypes, as their main contribution in the project was not the study of the functional parameters but to better understand the design goals of this design iteration. This deeper understanding leads to a next iteration with less abstract design goals.

As far as the projection is concerned, the results of the paper prototype were very much in line with those of the ceramic prototype. However, the way the two different forms were lit created two distinct experiences. This diversity supports the position that the materiality of the artifact is entangled with the luminous atmosphere it creates and they both have to be addressed holistically to robustly achieve the design goals set.

Reconceptualization of Atmospheric Luminaires

An atmospheric luminaire, in the context of this study, is an artifact that creates the feel of a space through the creation of dynamic luminous qualities interlaced with the reactions of the people in said space and the environment. At the same, time this created atmosphere inspires different interpretations, depending on the person and on multiple phenomenological sensory data based on personal memory and subjective experiences, making the users of the atmospheric luminaires co-creators of the atmosphere and thus, the environment.

Any light source, apart from those supporting the essential activities after dark, implicitly or explicitly incorporates the creation of an atmosphere (Bille, 2013). Subjective assessments of how a luminous atmosphere is experienced requires personalization and do not allow a design method that aims for universal acceptance. Nevertheless, all experiences are, to some extent, rationalized, understood and harnessed by design (Chapman, 2012).

Experience is the context in which, through some interaction, a person's emotional processes are activated (Chapman, 2012). Something similar happens in an atmospheric context, since the phenomenological approach of Schmitz sets the atmosphere as a reference to everyday experiences (Böhme, 1993; Schmitz, 1964). An experience can therefore arise due to the existence of a particular atmosphere while respectively the existence of an atmosphere can affect the interpretation of experience and its overall impact, positive or negative (Anderson, 2009; McCormack, 2014), due to its ability to absorb the very context in which it emerges (Edensor & Sumartojo, 2015). In conclusion, critical observation of the experience and the analysis of the behavior of the participating parties which (Chapman, 2012), through their interactions, contribute to the creation of the atmosphere is necessary to use these notions in the context of designing.

In this case study the primary experience that can be broken down into individual elements is the interaction between the user and the atmospheric luminaire. These elements can therefore be combined in order to form the basis of the design approach.

1. Dual nature (material and immaterial)

The outcome of the design process should embrace the materiality of the light source and the immateriality of the lighting effects produced through their interactions. The dual nature of light between material and immaterial enhances its performative qualities, making it a powerful element in alternative lighting design practices that aim to create experiences and meanings (Ebbensgaard, 2015).This became clear through first experimentation because the way the artifact was lit make its form more interesting. Also, the artifact’s characteristics referring both to the physical body and the projected results.

2. Dynamic form and affect

The extended dynamic force of a luminous atmosphere affects the sensations, materialities, emotions and meanings that are all enrolled within its field (Bille, 2013; Edensor & Sumartojo, 2015) and enhanced through skillful and inventive use of illumination, shadow and their absence (Edensor, 2015). This implies a developing variety of lighting effects and also the need for a dynamic form of the physical artefact that will be reshaped by the interaction with the user. For example, the dynamic element of the ceramic periscope of first experimentation is its capacity to change lighting effects, depending the slide selected.

3. Active user participation

Dufrenne (Dufrenne, 1973) is referring to the ‘atmosphere’ of an aesthetic object as its affective quality to elicit the feeling that the user ‘completes’ and ‘surpasses’ it. This happens because of the atmosphere’s “unfinished character” and openness to “being taken up in experience” (Anderson, 2009). During the user experience with the artifact, the user should be aware that he act as a co-creator of the atmosphere. This is became clear through the first experimentation, where the researcher noticed that the interesting part of the interaction with the artifact was not the projected result itself but the fact that it could be manipulated.

4. Immersive user experience

An immersive experience is described as a state that the person is completely occupied with something, giving to it all his time, energy or concentration. If this experience involves a physical object, the user is in a kind of meditative trance, where all conceptual barriers, material and immaterial, are overcome leading to the creation of oneness between the subject and the object (Chapman, 2012). The fact that the interaction with the artifact of first experimentation, gives the sense of being in a play, focusing on the process and not on the outcome, could considered also as an immersive characteristic. The way light shapes the environment enhances the atmosphere's immersive power (Thibaud, 2015), blurring the lines between luminous atmospheric object, subject and space. This enables atmospheric lighting applications to create the potential to influence a person's mood in contrast to other design applications that have external focus (Desmet, 2015).

5. Tangibility

The way that the interactions with the user are designed should take advantage of the materiality of the light source. The manipulation of physical objects stimulates more senses providing a sense of control and pleasure that defines the way they are felt and perceived. "The best of products make full use of this interaction" (Norman, 2005). The whole concept of first experimentation lies on the need for "physical" manipulation of light.

6. High levels of empathy

Design for emotional durability is grounded on the need for empathy that supports mutual evolution between the object and the subject (Chapman, 2012) and suggests the creation of artifacts that have multiple layers of functions and meaning that foster a subject-object relationship between effort and reward. During the interaction with an atmospheric luminaire, the effort is based on physical interaction with the material object that also affects the qualities of the generated light, involving the co-creation of the atmosphere. This interactive co-creation is where the reward lies.

7. Transparency (in the context of use and creation methods)

Contemporary artist Olafur Eliasson points out that "in order to achieve a challenging engagement with art that avoids the manipulation of the viewer, every part of the construction behind the presentation of art must be made a transparent part of that presentation." (Tiffany, 2008). Similarly in many works of 'Light Art', mechanism is an integral part of the composition that allows the viewer to build his own critical view upon the work and its meaning (Wedekind, 2011).

Design Approach

The proposed stages of the design of atmospheric luminaires are based on creative process (Wallas, 1926). Each iteration of the design process is made up of the following stages:

- Inspiration
- Ideation
- Experimentation

Between these stages reflective processes of feedback are undertaken, as well as a collective reflection of the design cycle as a whole.

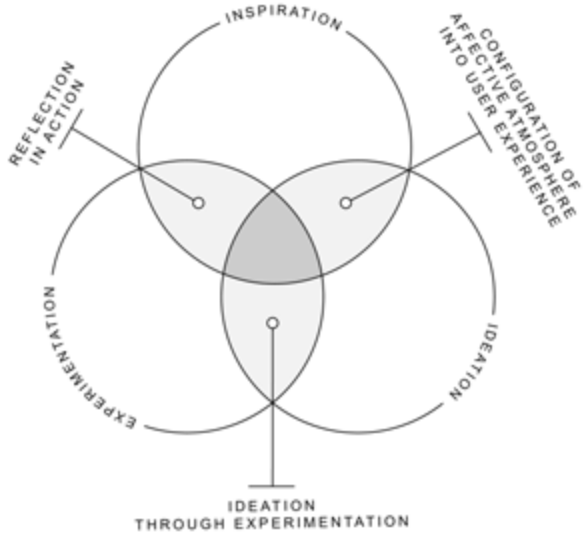

Fig 4. A schematic approach of the interactions between the stages of the design process of atmospheric luminaire artifacts.

Inspiration

During first design experimentation, it became clear that the basic concept, is rooted in previous experience of the designer, which is then embodied into an atmospheric luminaire. This embodiment process was implicit, making it necessary to analyse it in order to deduce the source of inspiration. Starting from the analysis of the personal experiences of the designer, one can find notions that can inspire.

The designer must be open and observant to outside stimuli, experiences, and all aspects of daily life, as they can be a source of inspiration. The stimuli arise from the environment, from one's past memories, discussions, from the actual design process itself, but also from the combination of seemingly unrelated memories and contexts. This is illustrated in the mindmap of the first experimentation. The mapping process seemed particularly useful for recognizing the experience that will be used. The way in which it took place is reminiscent of Freud's dream analysis, as the objective is not decoding the experience, but its recording and analysis through free associations, and everyday analogies allowing the meaning to emerge through verbal connections and of consciousness (Freud 1913; Bishop, 2005).

Ideation

At this stage the details of the experiences selected in the previous stage are transformed into design ideas, focusing on creating an atmospheric luminaire. A key feature of such artifacts is that they embody the personal experience of the designer through their physical form and their light qualities. This experience is completed by the observer according to the way in which they perceived the conceptual characteristics within the created atmosphere.

Given the anthropocentric nature of this approach, the designer should try to understand the unconscious processes that will happen during the interaction of the user with the object (Nimkulrat, 2012). With the selected experiences as a basis, we will explore ways in which these can be translated into design features of the artifact, which fulfill the general characteristics of this study.

In the first experiment, it was shown that the construction stage can provide new ideas on the design. Therefore, we propose a continuous feedback loop between design stages. To achieve this, the ideas developed during the ideation stage should not be analyzed in detail, nor be completed at the same stage but subsequently evolve during the experimental stage. This process is to be repeated until the desired results are achieved. The experiential practice-process works as dialogue between the potential of the situation and design goals.

Experimentation

In most design cases, sketching is the most common intuitive tool to express ideas in early development stages (Ingale, 2016). In this specific design context, where the physical aspects of the artifact should be developed considering the immaterial aspects of emitted light, the need for lo-fi early stage prototypes emerges. This became evident in the context of the first experimentation, where the interaction of the designer with the materiality of the artifact was led quickly to design solutions that take tacit knowledge into account. (Nimkulrat, 2012).

James Turrell in an attempt to explain how light can be formed concludes that "the form helps you form it" (Turrell, 2013). Here lies the value of having physical prototypes, since it enables the designer to "tactile light perception" and to manipulate the interactions between the components of the artifact through physical interaction.

At the same time, even though digital media prototyping could calculate the light parameters and reach satisfactory renders of light effects, they are not consistent with the phenomenological dimension of atmospheres, referring to the embodied experience created by the elements of the environment, the physical presence of the user, and motion within the atmosphere (Nimkulrat, 2012).

Reflection on the Design Approach through a second design experimentation

This current design experimentation is independent from the previous. The creative process starts with a completely new design idea and continues by following all design steps that proposed on the design approach. The goal of this process is to clarify the design framework and give new insights for further development.

Fig 5. A moodboard from personal images of luminous atmospheres.

During the stage of 'inspiration' the designer-researcher tries to observe the sensorial elements of the environment. This observation is supported by photographing moments involving light play. The reflection on past and present experiences, even though they don't always include luminous effects lead to a deeper understanding specific qualities of the atmosphere within these experiences took place.

Below, is presented one of the selected experiences and referring to the interaction with an object called 'magic cube'

Fig 6. A “magic” cube.

Mind mapping is used again in order to understand the connections of sensory elements that characterize this experience.

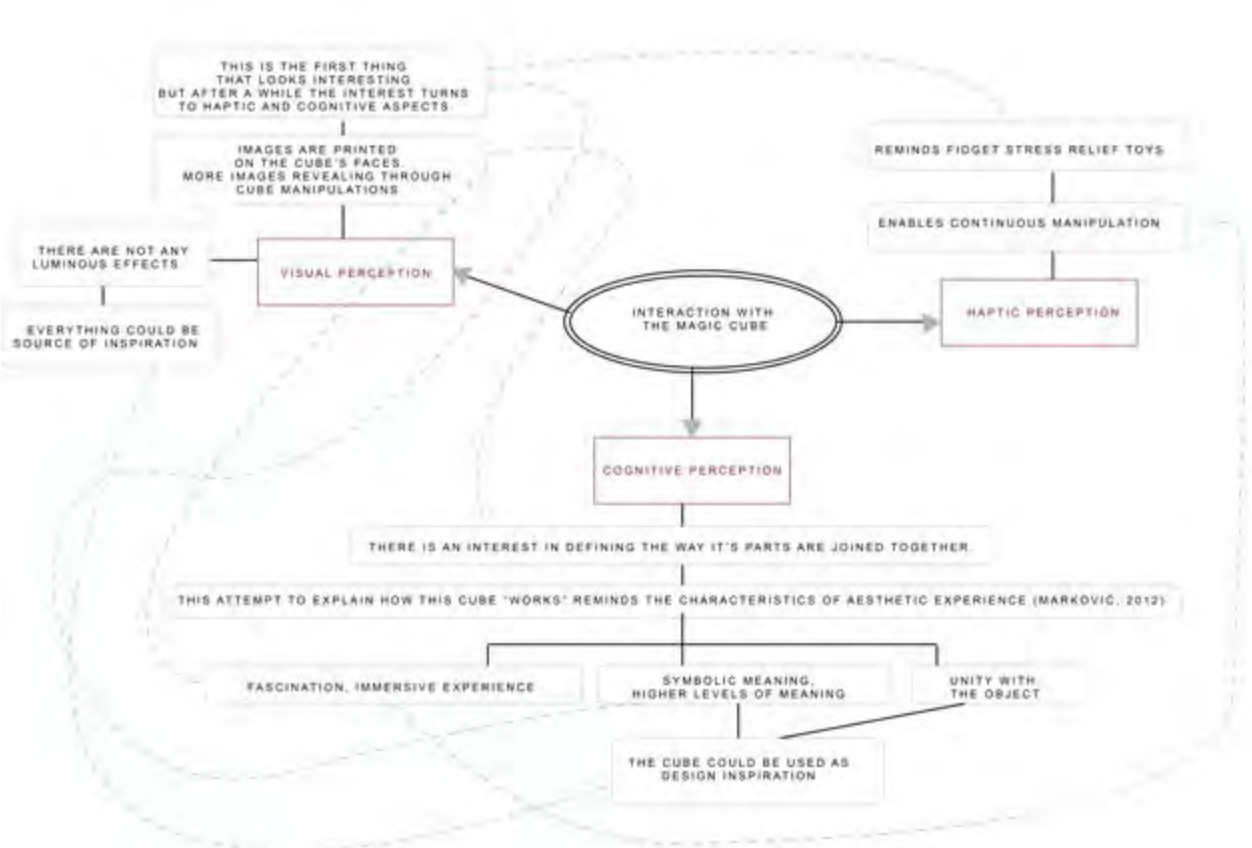

Fig 7. The connections of sensory elements that characterize this experience.

Continuing with the ‘ideation’ stage, a more focused search of the design possibilities of this experience took place. The basic characteristics of this experience, in relation to the characteristics of atmospheric luminaires, is tangibility and dynamic form. Thus, there has been an attempt to find design solutions to approach the rest of the design characteristics.

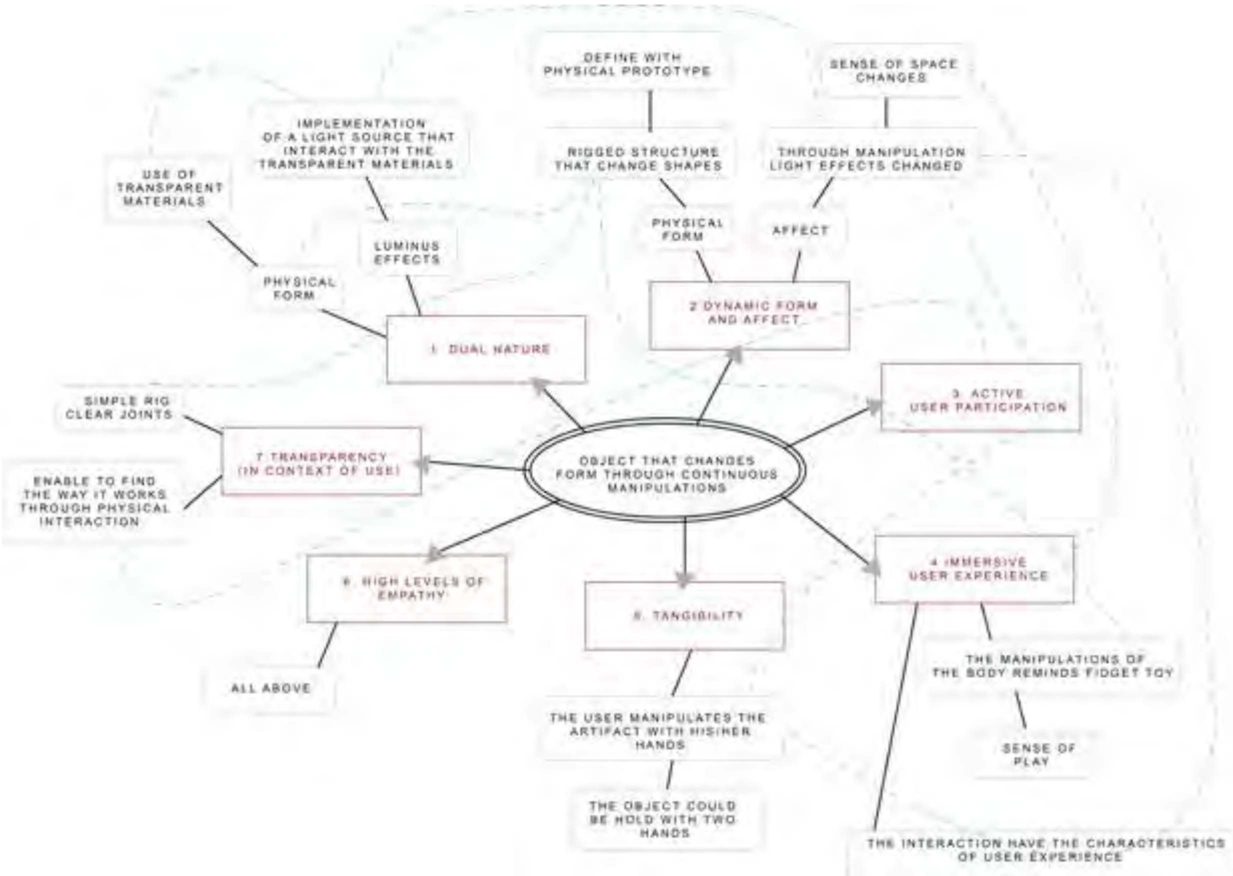

Fig 8. Mind map of design suggestions based on the characteristics of atmospheric luminaires.

The design characteristics of atmospheric luminaires derives from various cognitive fields that are interconnected. This became clear in the way the suggested design directions are related, and appear to address multiple characteristics.

To sum up, the core idea of this concept was the creation of an artifact that will possess the capacity to perform movements and change its form like a kinetic toy where its continuous movements affect its lighting effects. This concept needs a rigged artifact, which contains a light source, and parts made of transparent or reflective material (e.g. acrylic sheets). As the shape of artifact changes, it will produce different light patterns that alter the environment and affect its atmosphere.

The approach of the original form of the object described, is difficult to visualised through sketching so the stage of ideation took place through experimentation, making it difficult then to recognize what stage belongs to every action. The following table shows the manufacturing process.

	Model no1	Model no2	Model no3	Model no4
Pictures				
Goals	• Define Joints	• Formalistic Aproach	• Experiment with acrylic sheets • Define rigg • Static Study • Integrating the light source	• Tests with colored acrylic sheets
Materials	Plastic straws, wooden sticks	Pvc sheets, wooden sticks, fimo, glue	transparent acrylic sheet beech pegs, electric circuit, screws	colored acrylic sheet beech pegs, electric circuit, screws
Reflection	• No need of a ruler • Easy evaluation and correction of the set-up	• Enables movement tests through physical interaction • Used as a guide for next models • The artifact used as a form of comunication	• Approaching the the synthetic connectivity • When placed in an living space its "aura" changed • Enables the evalua-tion of physical interaction • Static study through tryal and error	• The construction was easier but less exciting than the 3rd • The lighting effects was intresting and there was a sense that the artifact embodies the whole research • Its observation led to new ideas for modifications
Possibilities and Limitations of the Materials	• Available at home • Enables easy modifi-cations • No formalistic approach	• Easy to find • Easy to craft • The flexibility of the sheets does not allow static evaluation • The sheets are opaque and don't allow lighting tests	• The materials are not only for lo-fi models • There is no use for special equipment for the construction • Clear-Transparent sheets don't produce very intresting lighting effects	• Colored acrylic completed the atmospheric concept • Red acrylic sheet absorbed light

Fig 9. The creation process happened during second experimentation.

Experiments for the behavior of the components in relation to the light were undertaken throughout the procedure, not only in the final assembled artifact.

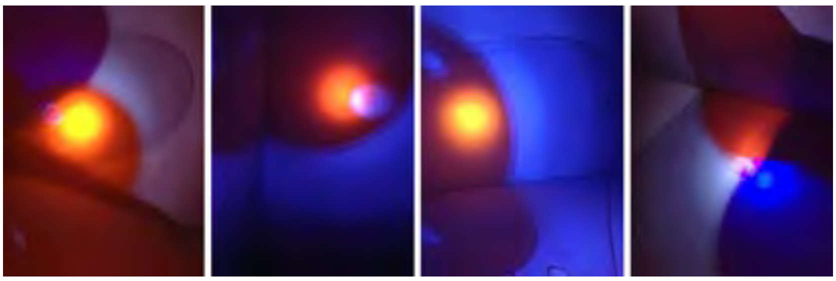

Fig 10. Projection experiments with the colored acrylic sheets.

Regarding the experiments with transparent acrylic sheets, which were not manufactured from new acrylic sheets or cut with specialized tool, the results are more interesting than expected, since light ‘highlights” all the imperfections of the material, which occurred during lifetime and its processing.

Fig 11. Projection experiments with white-transparent acrylic sheets.

During the experimentation with the colored acrylic sheets, projection tests with other light sources took place, which led to the observation that, as the light source changes, the results vary greatly.

Fig 12. Projection experiments with different types of light sources.

Reflection on second experimentation

Fig 13.The luminous effects of the final artifact.

In this experiment, the implementation is based on the potential of the situation, initially utilizing materials and expertise that are readily available, and then when run out of available resources alternative solutions are investigated. The acrylic sheets are easy to manipulate, which played an important role in using them, given that the construction did not take place in a properly equipped workshop. The conclusions of the first experiment, regarding the availability of materials and expertise, play an important role in the selection of individual solutions, concerning how necessity is the mother of invention.

As noted in the previous steps, the development of any construction stops at some point and a new test with different materials is carried out. Material based experimentation aims to study specific elements which evolve parallel to the original idea. The fact that the use of materials helps to achieve a design goal, makes it difficult to start over and study another. Thus, their possibilities and limitations define the end of one design cycle, and their replacement leads to the beginning of a new design iteration.

In the first experiment, we highlighted the need for experimental implementation of artifacts due to the experiential understanding of the interaction of light with selected materials. The present experiment confirmed this conclusion. Because of the higher fidelity of the produced prototype it was more beneficial for understanding the overall relationship of the generated light qualities in relation to the artifact, the space and the subjects located around it. Specifically, we observed that small changes on the selection of materials and components, significantly affects the overall effect in unexpected ways.

The two artifacts, through their physical structure, reflect the way in which they were created embodying the whole experiential research and all attempts to connect the individual cognitive and physical components. This exploration through materials and the manner in which they satisfy the characteristics of the framework can be realized in both visible and tactile manner. The apparent depiction of the creative process in the form and composition of artifacts, contributes to achieving high levels of empathy. (Niedderer & Townsend, 2016).

Fig 14.Photo of the final artifact.

Finally, these artifacts can not only be characterized by their capacity to develop the design tool through their creation. With some improvements, can stand as independent, functional atmospheric luminaires.

Conclusions

During this study we got to understand the concept of luminous atmospheres and search ways to convert it to user experience. The design of atmospheric luminaires is approached interdisciplinary, with particular emphasis on the integration of the experiential nature of light during the design process, trying to approach a seemingly visual experience with the whole body, a notion that phenomenology address as the “embodiment of vision”. The intimate relationship between object and subject leads to an experience, which refers to phenomenology, that emerges through the process of crafting the concept with the thinking body, but also because of interiority that characterizes the relationship between the author and artifact in the creative process. The understanding of both conscious and unconscious actions that took place during the experimental process, has significant potential both in the design process through inspiration and knowledge production.

Treating an objective non-material medium like light as a material, requires a certain level of abstraction, thus the proposed process aids to create broader understanding of the concept of materiality, which can also could be applied to provide useful conclusions in the design of not only physical objects.
The approach of the design tool, describes the creation of ambient lighting object as a particular internal and personal process. For further development of this research, it would be beneficial to carry out a study on the development and evaluation of the design tool in a co-creative context that appeals to a design team.

In conclusion, it would be interesting to study the technical aspects of design techniques required, seeking ways to smooth their integration into the design while maintaining the subjective experiential character design analyzed, thus reaching full range of design needs for integrated design results.

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//Synthetic. Reflective. Mnemonic: speculations on the materiality of the hybrid real

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Abstract

Historically, the notion of materiality has been used to represent the connection between our bodies and the physical world. However, in the recent years, with the emergence of the digital realm, the mere physicality of our connections ceases to capture the multifaceted reality in which we exist, thus acknowledging actual materiality to be ever more volatile and immaterial. In the space where the physical and the digital bleed into each other and in the time when the simulated image overlaps reality, materiality is, therefore, re-conceptualised; rather than being bound to the physical or the digital, materiality is construed to be extended towards a virtual co-existence between subjects, objects and environments that occupy both -and at once- the physical and the digital domain. This paper investigates the dynamics of materiality's emergence in the hybrid space between actuality and virtuality and it, further, envisions contact zones between the tangible and intangible forces that act upon space.

The paper adapts an energetic approach towards materiality. Through three speculative scenarios,it advocates for a transformative materiality which embodies unexpected intimacies and is able to fabricate new material narratives. By focusing on the concepts of affect, resistance and effect, the paper will demonstrate that, in the space of hybrid interaction, matter is not only active but also alive and adaptive. Through the assembling and disassembling of matter, we will follow the movement from virtuality towards actuality -and vice versa- and we will explore the space of possibilities that this passage opens up. In this process, we aim to challenge our understanding of the “other” and question our relation to reality.

Keywords
materiality; actual; virtual; affect; resistance; effect

What is materiality? How do we encounter it? And what is our relation to it? In the “material dialogues” of this study, these three research questions hold a key role. Matter is put, here, under the microscope of today's physical and digital coalescence in an attempt to register the dynamics of its emergence and the degree of its performance within the hybrid space. By focusing on the intimate and unpredictable ways in which matter emerges, this study advocates for the re-conceptualisation of its agency in the entanglements between subjects, objects and settings, and makes a claim on the space of possibilities that this re-conceptualisation opens up.

The argument for a critical understanding of materiality that this study presents, unravels here under the umbrella of two broad categories: i. that of "paradigm shift", as the new model for understanding and experiencing the physical-digital interaction and ii. that of "speculation", as the strategy that formulates hypotheses for change. The two categories construct the conceptual framework of the study and serve as the latent threads that permeate all of its layers and enable alternative perspectives to be posited.

The methodological playground of this study is set upon three hybrid what-if scenarios that link the idea of "speculation" with that of the "paradigm shift". These scenarios formulate a philosophical approach towards materiality that is informed by readings of a multitude of theoreticians ranging from Ponty and Deleuze to Boscagli, Bratton and Scott. The structure of the transcendental space -that the scenarios stage- functions as a feedback loop between projections and creative processes. By deconstructing axiomatic or fundamental perspectives around matter, these "material dialogues" speculate upon the possibilities that arise from a non-deterministic engagement between properties and capacities of both the physical and the digital domain. The unconventional configurations that the scenarios propose create, then, an expanded field of forces that enables us to re-conceptualise the entanglements between subjects, objects and settings. In this sense, instead of predicting or forecasting the future, the what-if scenarios serve as a critical tool to redefine our relation to reality; by highlighting limitations they trigger imaginative composite tectonics.

Scenario 1_ Synthetic materiality or What-if my voice could shape the giant vase

I stand in front of a terracotta vase, whose size is almost like my size. Subconsciously, I start thinking of it less as an object and more as an other being occupying the same space as I do. In my mind I work out the possibility of me and it – or maybe I shall say us- starting a dialogue. I wonder what if the vase could listen to my voice and respond to it in some sort of fashion? I wonder what if my voice could shape this giant vase, and what if it could do this over and over again until that point where I finally find myself immersed into it?

The space in which the previous scenario resides is a space of propagation and effects. Its anexact geometry (Reiser and Umemoto,2006) -the result of forces on matter (Fig 1, Fig 2)- stages the encounter and tests the reactivity between subjects and objects that are conceived as to equally participate in the act of morphogenesis. By recasting received notions of "sovereign form/passive matter", the scenario proposes an understanding of space as a performative field of forces and events. In the context of this space, matter itself appears as an emergent condition. It is a "temporary aggregation that collects in events" (Boscagli,2014) and bears the imprint of interaction between quasi-subjects and quasi-objects (Boscagli,2014) whose properties and capacities come together to activate a new transformative materiality.

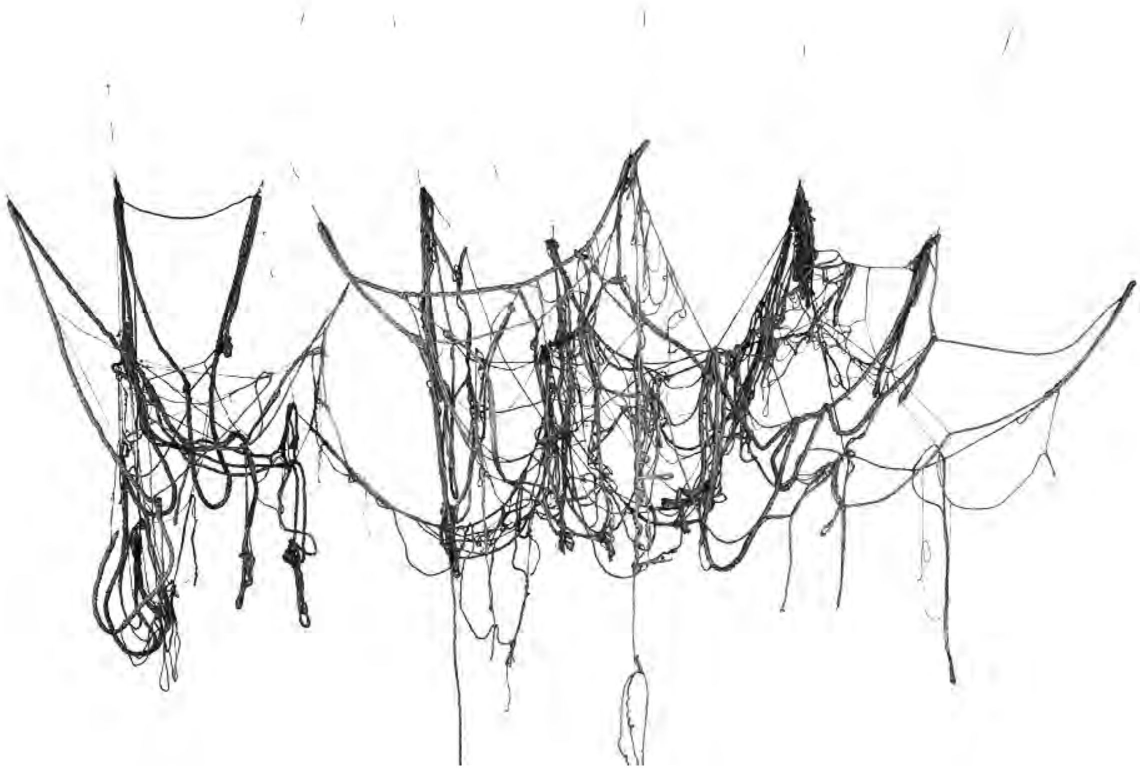

Fig 1. Eva Hesse- “Abject Materialities”
source: https://thefineartofabjection.wordpress.com/2015/02/05/eva-hesse-abject-materialities/

Fig 2. Robotic catenaries
source: http://m4h.hyperbody.nl/index.php/Msc3G3:Group

“Synthetic materiality” describes, here, the emergence of matter as the result of the plastic subject-object relationships. Deriving from the greek word synthesis -which means bringing different parts together into a composite whole- the new materiality performs as a kind of merging process between the quasi-actants. This means that the process binds together the subject and the object which “need each other -not in the Platonic sense to complete one another in a state of perfection- but rather to reflect one another”(Flusser and Bec, 2012)

In this sense, the dynamics and the continuities of the two parts create an intensive field of forces which inscribes the actant's actions into their material expression. Thus, the synthesis of the matter becomes the assemblage of such forces acting upon space. “Synthetic materiality” is not, however, a mere accumulation of energies. Rather, it is a topological organisation which identifies tendencies in order to structure them into a possible becoming form. “The energetic of this anexact form manifests itself through its intensive variability”(Reiser and Umemoto, 2006), a kind of internal intensity based on local proximities.

In the sequence of these actions “synthetic materiality” holds inherent tectonic qualities- it is the art of giving shape to invisible or unpredictable affects while sustaining its relevance to the visible properties and capacities of the matter field in which it resides. In this sense, “synthetic materiality” performs as a synthesis in itself -it plays out as a simultaneous suspension and exposition of the act of creation and, in doing so, it becomes both poiesis and praxis.

Its tectonic expressions take, then, the form of a feedback loop between creativity and projection which carries the potentiality of the subject-object encounter out to actuality. This feedback loop can be better understood as a dialectical process of creation and resistance (Agamben, 2014). In the poetic act of making -that the object and the subject share- the ability of the one to influence the other is co-present with the inability to do so. The field of tensions between quasi-subjects and quasi-objects is, therefore, one that expresses itself while resisting it.

How does, then, “synthetic materiality” resonate with today's digital tectonics? How does it relate to the hybrid domain of physical-digital coalescence? And what kind of possibility spaces arise from the “superimposition” of the physical-digital layer on the subject-object one?

In this case, the space in which the initial scenario resides becomes a hybrid space of propagation and effects. The materiality of such space is intended through the hybrid relations between subjects and objects that are mediated by their physical and digital states and give rise to a new kind of reality. In the context of the hybrid space, the new real -i.e the hybrid real- appears as an intermediate space wherein the act of creation embraces the suspension of the linear subject-object schema and expands the binary field of interaction towards an open-ended field of possibilities. (fig 3)

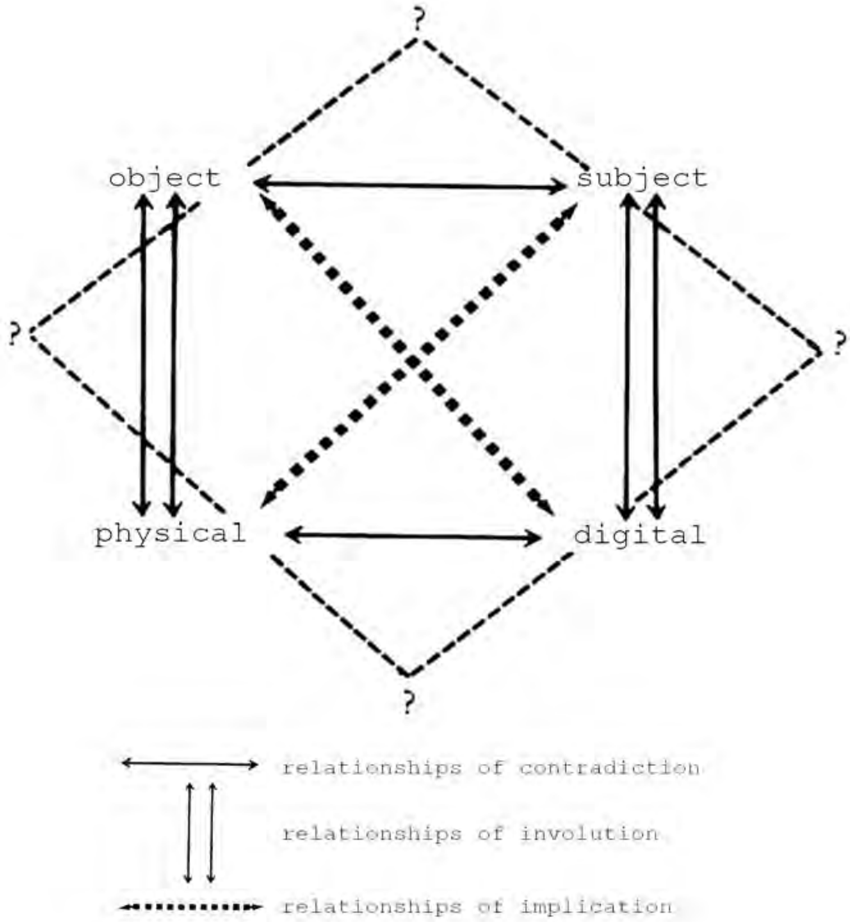

Fig 3. The expanded field. (Re-drawn by the author from Rosalind Krauss' diagram)

To understand the function of such field Deleuze's notion of **"**affect**"** is key."Affect" is an element's ability to form heterogeneous assemblages; whether the element is an object or a subject the concept reflects its very capacities to affect or to be affected by others and, therefore, reveals its agency in the formation of complex configurations that are part of more extended systems. In the context of real space, these configurations are the result of the merging between capacities and properties that are inherently physical. In the context of hybrid space, however, with the physical and the digital bleeding out and into each other, previous properties and capacities are enhanced by the emergence of new unexpected kinds. The emergence of new forces is bound to the virtual space and only extends towards the physical or the digital in moments of actualisation.

In the voice/vase scenario this augmentation of properties and capacities -enabled by the hybrid real- allows for the exploration of an array of possibilities that challenge our relation to both reality and its design process. This exploration is based on the interaction between two kinds of spaces: the existing space of the tangible vase and the constructed space of the intangible voice. The two spaces enter both the physical and the digital domain through processes that not only interface but also augment the ways they perform.

A recent experiment on such processes at the RCA has explored the use of code for the formation and the manipulation of the physical and digital interconnections in the 'voice/vase' scenario. In the implementation of code as a design process, both the vase and the voice undergo perceptive alterations that enable them to interweave in irregular ways. The physical space of the vase is translated into its digital image of a 3D pointcloud; similarly, human voice is extrapolated as sequences of different frequencies and is mapped onto the 3D digital space in the form of a soundwave. (fig 4)The coding process is, then, deployed to superimpose the two elements and explore the space of possibilities that the creative process opens up. The superimposition, however, of the vase-pointcloud and the voice-soundwave allows for the emergence of an augmented set of properties and capacities. The original 'voice/vase' scenario is mediated by its digital equivalent –the 'pointcloud/soundwave' scenario-, thus creating the extended schema of 'voice-soundwave/vase-pointcloud'. In the case of the first half (voice-soundwave) the design process enhances the capacities of the voice by enabling it to manipulate the vase; similarly, in the case of the second half (the vase-pointcloud) the process provides the vase with a new property -that of being manipulated by the voice. The manifestation of these intricate, unexpected and, even, somatic relations between the hybrid actants rests, however, at the level of performance where "synthetic materiality" finds its place.

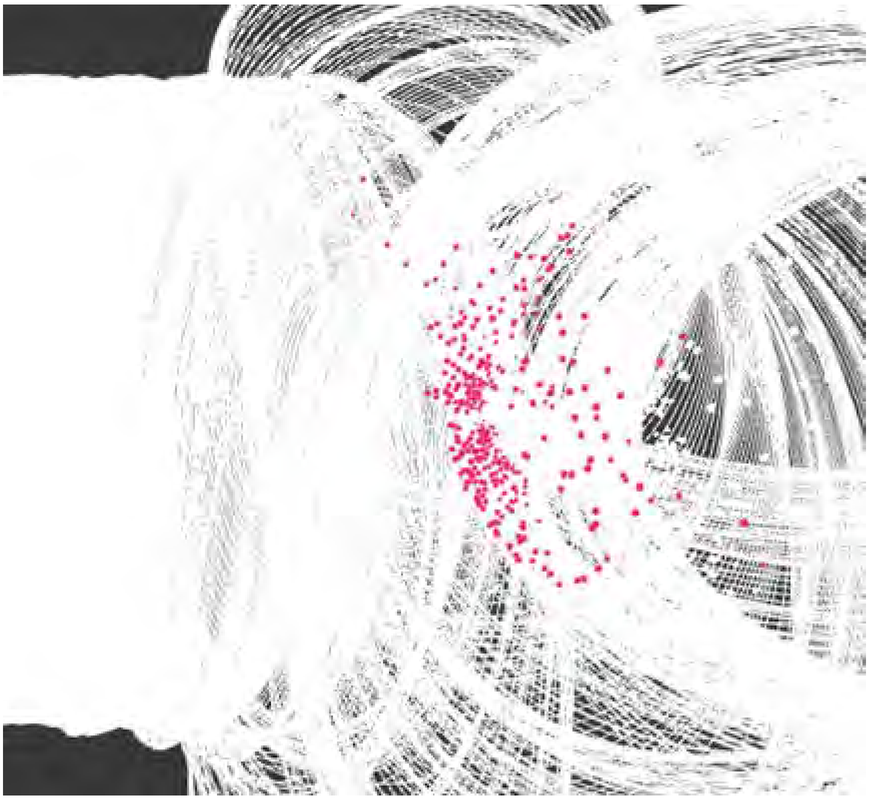

Fig 4. "voice-soundwave/vase-pointcloud" (author's project)

In the context of the above scenario, "synthetic materiality" is proposed as one that re-conceptualises the relationship between the subject and the object and proliferates into their unpredictable intimacies. Degrees of difference or proximity unravel onto a topology of possible forms that are enacted in and through local processes. The internal variability of the 'physical-digital/subject-object' system acknowledges, then, matter to be always becoming. This means that, materiality performs upon these forms as "substance in flux"(Boscagli, 2014) and that it, moreover, reveals the synthesis of the hybrid actants through the degree of its performance. Thus, the form emerges from the processing of the exchanged information and is subject to the speed or rate of their interexchangeability. Tin this sense, what is being modelled here "is not only objects or environments but also the invisible forces that act upon them" (Ferrarello and Walker, 2016). The virtual interactions of the subject and the object are, thus, recorded and mapped onto the real space in -new and coded- forms that represent the process of their becoming and are expressed through the physicality of their material being. The process of making – or else materiality as an act of creation- becomes, then, the movement from the virtual space of interaction towards that actual space of manifestation.

The different levels of entanglement between the hybrid actants include all the potentialities of the system. The possible becomings are, in this sense, the latent threads of the self-similar structure which might be affected one way or the other to generate actual forms. Through these causal interventions the virtual is actualised, thus revealing a new space of possibilities to push further the initial structure. The formal outcome of the process, as a result of a particular "affect",is therefore never pulled out and away of the system; contrariwise, "synthetic materiality" and "synthetic tectonics" incorporate it as a new force in the expanded field that they inhabit. This infinite process of becoming is, then, one of a non-definitive nature and, as such, it prioritises possibilities over affordances. The conceptualisation of both the system and its occupants is, thus, a transcalar abstraction upon which the philosophical argument is built.

Scenario 2_ Reflective materiality or What-if my eyes could draw the landscape else

I lay back on my couch and drive my eyes towards the wall on the opposite side. My gaze is captured by the big window in the centre of the white surface which reveals, in all of its splendor, the world outside. I stay there for a moment, in a dream-like state, traveling along the lines and the horizons of this given world, imagining myself re-drawing with my bare eyes the image of this landscape. I stay there wondering what if this could be true? What if the landscape could feel the movement of my eyes along its surface and react to it by altering its image? I wonder what if this alteration could happen again and again, and what if in the end I find myself incapable of telling whether it is me who changes the landscape or the landscape that changes me?

The space of the subject-setting interaction as described above is -here too- conceptualised as a space of tensions and effects. The scenario takes root in appearances and resides in a spatial field of impressions. Its phenomenal place stages the shared experience between the subject and the setting and acknowledges the primacy of perception for the constitution of their material co-existence and their material re-creation. The scenario approaches materiality from within the sphere of the relative; the reflection of the subject into the setting and that of the setting into the subject is not construed as (pre)determined or fixed, but rather as part of a continuum that manifests itself at every moment. In the context of this quasi-spatial field, matter itself appears in flux; it flows as substance over the possible reflections and formations inscribing their tendencies and intensities. Thus, matter is, in this case, not only emergent but also alive as it embodies the passage from the impression to the expression, from the virtual to the actual, from the space of projection to the visible space, and vice versa.

"Reflective materiality" is, then, proposed here as the materiality of the transitional space of perception. It is not articulated as a different sort of materiality in opposition to "synthetic materiality"; on the contrary, its performance is conceived as a complimentary way of understanding and experiencing matter in the sense that the difference between the two materialities is not one in kind but one in degree. Thus, "Reflective materiality" does not suspend or abolish the act of synthesis as apprehended through "synthetic materiality"; contrariwise, it elevates it at the stage of co-existence. Therefore, in the processes which enable "Reflective materiality" to perform, beings are not perceived as (pre-)given entities but rather as reflective emergences or projections born through their interaction over time. This means that both the subject and the setting ,in which it is located, occupy dimensions that they, together, have formed in a presumption of their unity. In this sense, reflection operates as an abstraction machine that binds together the actual and the virtual and carries within it the potentiality of their existence; “the potential for them to be something and, at the same time, the potential for them not to be something”. (Agamben, 2014)

It is apparent, then, that in the perceptual field of “reflective materiality” the form is defined by the intensity of the forces operating on both sides (potentiality to/ potentiality not to) as well as by the degree of this intensity. For the form, then, to appear as an expression of these processes, reflection needs to master the impressions. This means that reflection as a structural phenomenon has not only to link but also to communicate the unique manner through which the subject exists in the particular setting. In other words, “reflective materiality” is, what is more, the expression of a spatiality that defines and establishes the subject-setting relations at every moment. Intensity, in this context, measures the strength of the effect that the interaction produces and, in doing so, becomes “the fuel for the morphogenetic process”(De Landa, 2011). The act of reflection becomes a simultaneous act of creation or, in other words, a praxis expressed in the form of resistance (Agamben, 2014). The capacities of seeing, doing or being resist those of not seeing, not doing or not being in a dynamic give and take between the subject and the setting. The tectonic qualities of such a resistance are, thus, inherent to the process to the extent that intensity is an inseparable element of the act itself. “Reflective tectonics” embody, then, the exchangeability of matter in a synthesis of inexhaustible possibilities.

How could, however, “Reflective materiality” perform in the sphere of the hybrid real? In what ways could a scenario where the physical and the digital coalesce unlock the transformative potentials of the subject-setting interaction? And to what extent could this scenario produce a new space of possibilities?

In the transposition from the perceptual space of co-existence to the hybrid space of propagation and proliferation, the material field -that both the subject and the setting inhabit- expands towards a virtual incorporeality. The hybrid domain performs as an eventual space wherein properties and capacities enter new relationships as they are mediated by their physical and digital states. This eventual, almost volatile, space stages the simulations of the actants' performance and gives rise to a materiality that constantly “projects content and scale into the unformed field”(Reiser and Umemoto, 2006) This means that matter does not appear, here, as a precise condition but rather as a generic tendency that could find its explicit form through particular intensities. The emergence of such a materiality allows, then, not only for the continuous transformation of the landscape but also for the expansion of the performance upon or within it. In this context, reflection, too, becomes a machine of superlinear abstractions that augments the body (subject) and its environment (setting). The creative capacities of the actants reflect, now, the expansiveness of the space in which they reside and offer an added quality to the affective condition of their prior synthesis.

In the eye/landscape scenario the augmentation of perception allows for the exploration of a wide range of spatial configurations produced and inhabited by the subject and the setting in unity. The spatiality of the hybrid actants, as well as the experience of it, is communicated through a shared reality that emerges from the two-fold state between actuality and virtuality. This means that the spatiality, that the subject and the setting share, is not only dependent on the appearances of the visible world but also -at the same time- it is subject to the creative capacities of the virtual body. Its materiality is, consequently, one that rests on the intensity of the spectacle's field and it is, therefore, capable of occupying different levels of reality in relation to the degree or the rhythm of its performance.

As in the case of the voice/vase scenario, here too, the manipulation of the physical-digital interconnection is processed through the implementation of a coding system [8] that enables their simultaneous appearance in hybrid space. Thus, on the one hand the landscape -incorporated into the digital domain- exists as a simulated image of the physical space; on the other hand, the receptive eye of the subject is flattened down to a digital 2D trace which follows the motion of its physical -and sphericalequivalent. In the context of hybrid space, the landscape's simulated image is continuously updated as raw (live) data feed into its prior state, while the intensity of the eye is being translated into regions of affect at every moment. Both these two elements operate, then, as forces on matter, as lines of resistance and gradients of effect that deliver the intentions of the co-participators to the performative space that they, instantaneously, formulate. Thus, in the context of hybrid space, the 'physical properties/ digital capacities'- 'digital properties/physical capacities' schema operates on different levels and in different modalities that allow for the deterritorialisation and the reterritorialisation of the subject in relation to the world. This means that materiality as a process of production not only “subjectifies” the landscape, but also “landscapifies” the subject in a game of mutual reflection. (Fig 5, Fig 6)

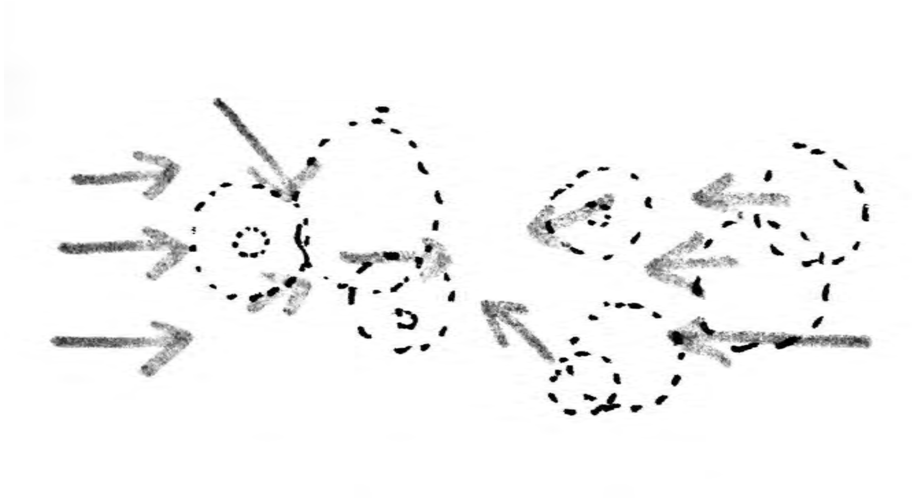

Fig 5. The intensive matter field (drawn by the author)

Fig 6. Diller + Scoffidio, Blur building, the building reshapes the landascape- the forces of the landscape reshape the building
source: http://www.dsrny.com/projects/blur-building

In this sense, “Reflective materiality” works as a dual operation, as a process that produces the one within the other, as a structure that connects the body-machine to the landscape-machine, and it, further, communicates this very connection. The dynamics of the material interexchangeability test, then, the reactivity of the subject-setting hybrid and challenge its physicality as the actants proceed into unexpected intimacies. The intensity of their interaction, the cumulations or disruptions of their material being, becomes the manifestation of the resistance -and the degree of resistance- that the hybrid space enables.

The forces of the two sides -recorded and mapped- model the potentialities of the system. Thus, the form emerges through this process in all of its contingency; it is a possible becoming that has absorbed both the subject and the setting in its being and it is, moreover, a representation -or, else, a reflection- of that absorption. This means that the possible form, when expressed, couples together the confinement of the actual and the expansiveness of the virtual, thus fabricating a new narrative that aims to “twist our perception of the material” (Boscagli, 2014). The conceptualisation of this profound contact between actuality and virtuality acknowledges, then, that possibilities are not external to the system, but inherent to the process as such. The possibilities are not just mere spectators but they, too, inhabit the spectacle.

Scenario 3_ Mnemonic materiality or What-if my mind could recreate it all

I close my eyes. I see myself holding tightly on a red jelly creature against a blue background. I pay attention to our clinging. My every move is followed by the jelly's move, my every action causes its reaction. I note its colour, its sound, the strength of its odour. I blink. I am a few steps away. The jelly is green and the background yellow. I can't hear any sounds nor can I smell any odour. I move my body and I see the green jelly moving back as if it were my mirror. I recognise this image. I blink. I cannot see the blue jelly any more. Its figure is lost in the orange background and its odour is weakened. I can only hear the song of its existence coming from far away. I recognise this sound. I blink. I had once met a jelly. I can't remember its colour nor its sound. But I'm telling you. This was exactly how it smelled like. I recognise this odour. I blink.

The above scenario resides in the perceptual space of virtual co-existence and conceptualises the intensive contraction within that space as an act of creation. Memory serves, here, as the material substance that intervenes perception and enables the contraction by producing actualities within the virtuality of the perceptual field. It is conceived as the inward experience wherein past and present fold into each other to produce levels of proximity in relation to the present, and it is, therefore, the means by which materiality performs in the interval between perception and reaction. Thus, matter becomes, in this scenario, attentive; it embodies the movement from the past to the present as well as the adaptation that this passage implies in terms of its intensive qualities. Memory is, in turn, inscribed into matter through the repetition of this movement, as the registration of differences -or proximities- in the process of passing from the one towards the other.

“Mnemonic materiality” describes, then, here the intimate relationship between matter and memory; it represents an active intentionality that embarks from recollection and proliferates into the virtual states of the possible becoming image. This means that “Mnemonic materiality” is not bound to the past or the present; rather it performs as a process through which the past restarts and repeats itself in order to materialise the possible becoming and expand it towards the, nonetheless, virtual present. In this sense, “Mnemonic materiality” is an appeal to actualization within the sphere of the virtual, and the intensity of this appeal indicates the degree of both “its contraction towards the past and its expansion towards the present”(Deleuze, 1991). Thus, each movement -from contraction to expansion- stages a different space of affect in which the capacities of the image -to be recalled and embodied- present a different aspect of the process that has led to its very evocation. Successions of this movement are, in turn, responsible for producing virtual repetitions that differentiate the intensive qualities of the mnemonic matter field. It is, then, in this sense that memory becomes an act of creation, an “act sui generis” (Deleuze, 1991) which unleashes unexpected tectonic capacities for the fabrication of a range of possible forms within a homogenous composition. These multiplicities are actualised as variations of this one whole which they always -virtually- co-exist with.

In the hybrid version of this scenario, “Mnemonic materiality” operates at the level of performance; it manifests itself through the experience of the space of interaction between subjects, objects and settings for which it triggers virtual material sensations. The digital real meets the physical real in the variations of these sensations that embody the elaboration upon the tangible and intangible information of the system. Memories -carried within these elaborations- perform as a medium for virtual reification; by extending the perception of the real they allow for the materialisation of the expanded virtual experience. Thus, in the course of this experience, “mnemonic materiality” emerges as the reflection of the subject-object-setting interaction which is, however, displaced and punctuated according to the requirements of each present moment. This spatial and temporal alternation -that takes place in the context of the hybrid real- enables, then, the generation of particular effects upon which the interaction unravels.

By entering the hybrid domain the subject-object-setting scenario takes the form of a parametrical system of production. All of the hybrid actants, together with their -physical and digital- properties and capacities, are translated into sets of information that can be recalled, processed and reconstructed at any moment. This parametrical system performs in a relational way; each set of information needs at least another set to activate the possible becoming image and inscribe it into the system. This fact acknowledges, then, that none of the system's elements has self-value or single-meaning and that, moreover, it is the combination of the system's parameters, the merging and blending between properties and capacities that allow -not only for the production but also- for the reproduction of the narrative. The local interconnections between these sets are, thus, inscribed into the system as explicit expressions of a particular sensorial event; once the event is expressed, it becomes -for the purposes of the hybrid interaction- both traceable and repeatable. Each image of affect is, therefore, able to migrate into different regions of the hybrid space where -combined with others- can create new and, even, unpredictable effects. However, since these images are traceable too, they are also able to form a structure of rememberance ; each event serves as the distinctive point of a specific level of affect which, by means of contraction (or expansion), helps to formulate the experience of the virtual.

Thus, in the space between virtual rememberance and actual narration, “Mnemonic materiality” functions as a generative force which embraces the strength of the effect. The embodiment of the virtual experience collects into an intensive version of the -previously impassive- images that the system has produced over time, and expands towards its actualisation through the traits that link these past images with the image of the present perception. It is, in this sense, the extent of the image's migration and the duration of its contraction that adhere to matter and enable it to be externalised as a possible present. The variations -that the displacement of the image produces- together with the movement -from one level of affect towards the other- induce virtual repetitions that manifest, at all scales and degrees, the tendencies and intensities of the mnemonic matter field. These patterns of matter's behaviour are, then, the ones to indicate the degree of resistance that the image encountered towards its actualisation.

The process of becoming -as the performance of the “mnemonic materiality”- reflects, in this sense, the possibilities of the image to become something of the present. The potentialities of its externalization lie on the continuum of this process that, by formulating patterns, gives content to the expression of the image in a total unity of the effect. The manifestation of the narrative through a single image becomes, then, the conceptualisation of the space of possibilities for which the “mnemonic image” represents the structural unit. The space of possibilities that this scenario advocates for is not, then, one of a delimited nature. The image-unit, which already presents a condensed version of virtual multiplicities, allows for the expansion of the expression in different modalities and with different effects. The space of possibilities is, therefore, an open-ended field.

Conclusion

Materiality holds in this paper an active role. Far from being construed as a passivity, as the consequence or the result of a particular form, materiality emerges as the force of formation in itself. The assembling and disassembling of matter -which is thought of to be enacted and performed stages the encounter between the hybrid actants and, moreover, facilitates the movement from the actual -i.e real-, to the virtual -i.e real but not necessarily actual- and beyond to the space of possibilities. Materiality unravels, in this sense, as a true act of creation; it is the process that makes -not just one but- all possible forms evident and subject to actualization, thus empowering creation and unleashing potentials for change.

As subjects, objects and environments constantly enter new kinds of relationships, this study has advocated for a transformative materiality that embodies unexpected intimacies and is able to fabricate new material narratives. The speculative "dialogues" of this study present, then, a materiality that is not only active, but also alive and adaptive. In the eventual space of hybrid interaction, this materiality measures the modalities of energy between the hybrid actants and it, further, extends the exchanged forces of affect, resistance and effect towards their actualization. Thus, in the movement from virtuality to actuality, materiality as an act of creation -or else as a potential for praxis- enhances the creative capacities of matter and challenges the physicality of both the form and its material being.

Through the dialectics of the actual and the virtual arises, then, the space of possibilities that has been originally claimed. In the infinite process of becoming -that the hybrid actants share- this study argues that the actual -as the externalization of the process- and the virtual -as the structure that allows for possible externalizations- co-exist in a twofold condition awaiting to be mobilised. Materiality appears, then, here as as an active intentionality; one that carries within it the potentials of the hybrid actants and, therefore, inhabits the whole potentiality of their interaction. Potentiality -in the form of speculation- is, then, thought of to be always present in projections yet to be enacted, in a future yet to come.

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On the Surface of Things: Experiential Properties of the Use of Craft Materials on Interactive Artefacts

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Abstract

Surface materials play a central role in the way we experience things. This is also the case with interactive artefacts, since the materials that are used for designing a surface or a casing will affect the ways in which the artefact will be physically interacted with and experienced as an object. In this paper we take a closer look at physical surfaces and study the experiential properties of different types of craft materials, which in our case are leather, textile, metal and wood. We look at how they influence the experience of interacting with an artefact by providing illustrative examples of interactive artefacts from our own design research, in which such materials have been used on their surface.

In order to do this we distinguish between three types of experiential properties based on Giaccardi and Karana's materials experience framework (Giaccardi & Karana, 2015), and on Fernaeus et al. action-centric tangible interaction (Fernaeus, Tholander, & Jonsson, 2008). These are sensory experience, physical manipulation, and interactive behaviour. The purpose with our distinction between the three experiential properties is to illustrate possible ways in which a craft material can influence the interaction with an artefact, focusing on the sensorial experience craft materials offer, how they afford particular physical manipulations in regards to the ways they can be given shape, and finally how they can offer interactive qualities based on their abilities to conduct, to resist, or trigger. We end by reflecting on the three experiential properties and discussing emerging topics that should be further considered when craft materials are used on the surface of interactive artefacts, in regards to craft values but also the social and cultural situatedness of surfaces and consequently artefacts.

Keywords

Craft materials; Interactive artefacts; Experiential properties; Leather; Metal; Textile; Wood; Surface;

Since computers can take very diverse physical forms or be embedded in any thing it becomes increasingly relevant to discuss how the physical appearance and the *surface* of interactive artefacts, can play a significant role in regards to the experience of interacting with tangible interactive artefacts (Janlert & Stolterman, 2015). Surface appearance has always been of fundamental importance in product design (Karana, 2009), whereas in interaction design studies have more recently highlighted this topic from a perspective of surface materials (Giaccardi, Karana, Robbins, & D'Olivo, 2014; Jonsson et al., 2016; Robbins, Giaccardi, & Karana, 2016). In this paper we are building on those studies in regards to surface materials, but we are focusing on a particular type of surface materials that we refer to as *craft materials,* here exemplified by leather, textile, silver and wood. We are referring to these materials as craft materials, because they are linked to a long crafting tradition that has evolved over centuries, including specialized tools and hands-on techniques for transforming each of those materials into utility objects. We find the combination of such craft materials with interactive technology to be particularly evocative for the domain of interaction design mainly due to the contradictory values between traditional crafts and computational technology, which are highlighted through hybrid crafting practices, aiming to combine these practices and materials (Golsteijn, van den Hoven, Frohlich, & Sellen, 2014; Gross, Bardzell, & Bardzell, 2013).

In this paper, instead of focusing on the concrete challenges of hybrid crafting, as discussed previously by e.g. (Perner-Wilson, Buechley, & Satomi, 2011; Rosner, Ikemiya, & Regan, 2015a; Tsaknaki, Fernaeus, & Schaub, 2014), we are looking at the experiential properties those craft materials can offer, when used as surface materials of interactive tangible artefacts. Specifically, we are presenting a series of illustrative examples from our own design research, in which leather, textile, metal or wood were used as surface materials of interactive artefacts, and we are providing an analysis of how each material with its unique properties may influence the interaction experience.

Our understanding of the notion of experiential properties is loosely based on the *materials experience* framework proposed by Giaccardi and Karana (Giaccardi & Karana, 2015) as well as on the *action-centric* perspective on tangible interaction, elaborated by Fernaeus et al. (Fernaeus et al., 2008). These works both point to how experience is shaped by a combination of sensory engagements with materials and actions that are contextually and socially situated in practice. With experiential properties we thus here refer both to material properties such as texture, being features of a physical surface that can be felt and experienced by our senses. But we are also referring to properties of a tangible interactive artefact that affect how experience unfolds in interaction, in regards to, for example, its interactive behavior. In the forthcoming analysis we are distinguishing between three categories of experiential properties, which are: a) sensory experience, b) physical manipulation, and c) interactive behavior. We are using those categories of properties in order to highlight the use of craft materials on the surface of interactive artefacts.

The reason why we chose those three is because they provide an account of experiential properties in regards to materials, while at the same time stress the importance of interaction. Specifically, sensory experience is used to describe the very particular sensorial properties of craft materials, which are also grounded in culture, and especially the tactile sensation. Physical manipulation is used to illustrate how craft materials, which demand a craft and hands-on approach on making, can inspire new design directions and guide design decisions, while at the same time provide a hands-on and tangible interaction gestalt. We will present concrete examples of how those craft materials can influence the experiential properties of interaction, and elaborate on what particular interactive qualities those craft materials can offer based on their abilities, for example, to conduct electricity, or to provide resources for digitally mediated actions, as triggers or buttons. We will end with a broader discussion on the use of craft surface materials on interactive artefacts and reflect on emerging issues in the intersection of interaction design and crafts.

Background

Materials play a central role in design practices, where acts of shaping or combining matter are involved. One such practice is interaction design, which concerns the design of interfaces, while at the same time includes the design of physical controls and devices. When talking about materials in this context, the definition extends from physical matter to immaterial, including software or code, apart from hardware (Blanchette, 2011; Fuchsberger, Murer, & Tscheligi, 2013; Lindell, 2013; Wiberg, 2013). There has already been a substantial body of work in studying the various material instances that expand from the mere physical to the fully computational and their in-between stages. One related topic of discussion concerns the blended materiality of the physical and computational, which forms a new material, with its

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own unique properties. An example of earlier research on this topic includes Vallgårda and Redström's (2007) c*omputational composites* , which are physical materials with additional computational properties of sensing and actuating. Similar research studies on materiality in interaction design point to the fact that artefacts can take various forms, instead of being predominantly screen-based, and they are no longer restricted by the clear distinction between physical casings and electronic components or computation. Other studies on the many facets of materiality and the design of interactive or electronic products have pointed to the fact that materials are not only affecting a product in regards to style and form, but they are also shaping social practices around it. The materiality of interactive artefacts in relation to the experience those materials provide are "shaping ways of doing and ultimately, practice" according to Giaccardi and Karana (2015, p.2447).

Craft Materials in Interaction Design

The combination of physical and computational materials has been also studied from a crafts perspective, often described as hybrid crafting (Golsteijn et al., 2014), or hybrid fabrication (Zoran & Buechley, 2013). In the interaction design domain there has been an increased interest in crafts lately, mainly highlighting the intersection of so-called traditional crafting practices with contemporary practices of designing with interactive technology. A number of researchers looked at what design can learn from values embedded in crafting (Bardzell, Rosner, & Bardzell, 2012; Bofylatos, 2017; Jacobs et al., 2016), while others speculated on the use of specialized tools for programming computation composite materials, drawing inspiration from craft practices (Vallgårda, Boer, Tsaknaki, & Svanæs, 2016). What is more, the resurgence of crafts in interaction design brought with it a focus towards craft materials such as glass (Schmid, Rümelin, & Richter, 2013), textiles (Buechley & Perner-Wilson, 2012), or ceramics (Meese et al., 2013; Rosner, Ikemiya, & Regan, 2015b). Such materials are often referred to as *traditional* in order to stress their relation to culture, history or to distinguish those from *functional* ones, as described by Vallgårda in the following quote:

> Traditional materials are those we all have direct experience with, and which has been around, if not since the beginning of time, then at least for centuries (e.g. wood, clay, textile, metal). Functional materials, on the other hand, are the designed materials that flooded the market after chemistry, physics, and engineering joined together in studying and improving materials (e.g. plastic, fiberglass, electroluminescent film) in what was to be called materials science (Vallgårda, 2009, p.52).

Similarly, leather, textile, metal and wood discussed in this paper belong to the category of traditional materials, since each has an old crafting practice dedicated to the art of manipulating it. However, in this paper we will use the term craft materials, in order to stress their relation to crafting, as a way of giving form to them, involving a set of techniques and specialized tools. Those craft materials have been used traditionally and until nowadays for designing a range of utility products, such as leather bags, cutlery or jewellery, clothes or cushions, but they are not so often used for designing electronic or interactive products. Additionally, they are mainly associated with small-scale making processes or with product design, and much less with the domain of interaction design. However, several studies in interaction design and more broadly in the field of Human-Computer Interaction conducted lately include craft materials, mainly looking at the concrete challenges of combining craft materials with electronic components (Buechley & Perner-Wilson, 2012). Other studies stressed the properties of craft materials in relation to interaction (Vallgårda, 2008), or explored new ways of crafting with personal fabrication tools (Tsaknaki et al., 2014; Zoran & Buechley, 2013).

Integrating craft materials in the design of interactive artefacts has been also discussed from a perspective of how such materials could act as eco-friendly alternatives to plastic composites for example, which today dominate the market of electronic products. Verbeek and Kockelkoren (1998) were perhaps the first to highlight the topic of surface appearance of products in relation to crafts and materiality from a perspective of sustainable design, but also in relation to concepts such as longevity and obsolescence. Finally, craft materials are embedded with cultural values, which might influence social practices and use contexts that emerge around them. Looking at the design of hybrid artefacts from this perspective poses new challenges for product and interaction designers in regards to the concrete choice of surface materials, which inherently guides the interactions performed with the artefacts (Fernaeus & Sundström, 2012; Giaccardi et al., 2014; Robbins et al., 2016).

Experiential Properties of Interacting with Craft Materials

In this section we present concrete examples of how the craft materials leather, metal, textile and wood shape the experience of interacting with artefacts, when one of those materials are on their physical surface. We will do this by distinguishing between three particular experiential properties: a) sensory experience, b) physical manipulation, and c) interactive behavior. We have extracted and adapted those three experiential properties from Giaccardi and Karana's framework on *materials experience* (Giaccardi & Karana, 2015) and Fernaeus et al. (2008) *action-centric* perspective on tangible interaction. The materials experience framework represents a dynamic relationship between materials, people, and practices, according to Giaccardi and Karana, and consists of the sensorial, interpretive, affective and performative levels through which materials (and through those artefacts) are experienced (Giaccardi & Karana, 2015). On the other hand, the *action-centric* perspective on tangible interaction, describes the qualities of tangible user interfaces as *resources for action*, and how this perspective may be reflected in design (Fernaeus et al., 2008). Fernaeus et al. distinguish between four types of actions on tangible interactive artefacts: physical manipulation, digitally mediated action, perception and sensory experience, and referential, social and contextual action. Our proposed experiential properties build in particular on three of these four types of actions, providing a means of analyzing the interaction with materials from different perspectives with respect to the role of the craft materials in interaction. We also incorporate the experiential dimension from the materials experience framework and in particular the relationship between materials, practice and experience, where we here emphasize the crafting practices as important for how the experience with the materials unfold.

The purpose with our distinction between the three experiential properties is to illustrate possible ways in which a craft material can influence the interaction with an artefact focusing on the sensorial experience craft materials offer, or on how they afford particular physical manipulations in regards to the ways they can be given shape. But also on how they can offer interactive qualities based on their electro-conductive properties, for example how they can be integrated as parts of electronic circuits, and what qualities this may bring to an interactive setting. Below we use the proposed material properties to analyze how the surface of interactive artefacts can be a resource for actions and sense making and how we may address those qualities, when designing interactive systems. The aim of providing those examples is to offer empirical material for other design researchers to reflect on the use of craft materials on the surface of interactive artefacts, but also to suggest ways in which the particular craft materials being in focus here, leather, textiles, metal and wood, can influence the experience of interacting with an artefact, in different ways. Most importantly, the presented cases should be read as illustrative examples, aiming to open the space for further discussions and studies on this topic, rather than as a complete analysis of the experiential properties of specific craft materials.

Sensory Experience

Tangible interactive artefacts can be physically experienced with our senses, through smell, touch or auditory feedback. The sensory experience is what Giaccardi and Karana referred to as 'sensorial level' on the materials experience framework (Giaccardi & Karana, 2015), but it is also related to the 'perception and sensory experience' of the action-centric perspective by Fernaeus *et al.* (2008). Being the only part of the interactive system that is seen, but also available to be touched, an artefact's outer physical surface holds special potential for triggering intriguing and evocative sensory experiences, especially in regards to the artefact's interactive behavior. For example a casing or the surface of an interactive artefact may be designed to shield off, modify or even amplify all kinds of output modalities, such as audio, heat or vibration that an interactive device may generate, through speakers, thermoelectric modules, motors or other components. As discussed by Jonsson *et al.* (2016), the physical sensations that heat or vibration modalities can evoke may depend on the choices of outer surface materials to a great extent, and can affect the sensitivity of different body parts or the degree of subtleness of the experienced interaction.

Example: Leather as surface material

Craft materials, as every other material, provide very particular sensory experiences, when used as surface materials of interactive artefacts due to their unique properties, which can be actively used for designing the interaction with an artefact. Leather with its intense smell and tactile properties, textile being soft and flexible, metal being shiny and cold material, and wood being rough and grainy. One example from our own design practice that illustrates how leather invites for tactile interaction, and how this sensorial experience influences the design decisions taken and the interactive properties of an artefact, is the *sound box* interactive table (Tsaknaki et al., 2014). In this example, the tactile properties of leather played a significant role in how the interaction with the sound box was experienced (Figure 1a). This table consists of a touch sensitive leather surface on the top, which reacts to pressure by playing different recorded sound files, when different areas are pressed. The tactile properties of leather, in combination with the curiosity of touching the leather surface in order to feel its texture and quality, invited for gently touching and stroking rather than hard pushing, when the sound box was tested at an exhibition setting in Berlin (Figure 1b). But since the leather touch sensitive input surface was designed for being triggered with a gesture of vertical pushing, rather than smooth horizontal stroking, the researchers involved had to adapt and re-design the interaction modalities of the table, in order to fit with the sensorial experience that leather evoked. This was done by adding capacitive sensors, which could be triggered with a smooth touch gesture instead of hard pressing. And more broadly, this simple example of using leather as a surface material of an interactive artefact provoked reflections on how leather, due to the sensorial experience it provides and the close-to-skin interactions it invites for, can be used for designing interactive experiences, that other materials, such as plastic or metal, could not provide.

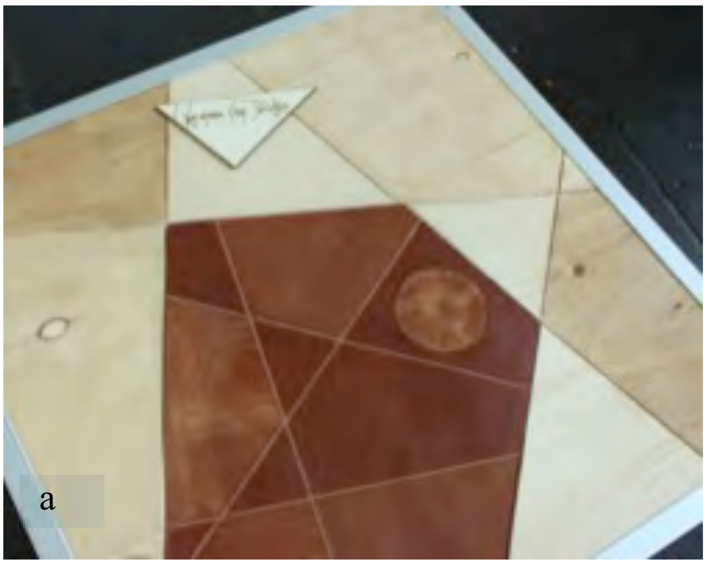

Fig 1. Leather used as a surface material for the touch-sensitive input surface of the *sound box*. The sensory experience of touching leather invited for gestures of gently touching and stroking, which played a significant role in how the touch-sensitive input surface was approached and interacted with.

Physical Manipulation

A central property of physical interactive artefacts is the ways in which they can be physically manipulated with hands and fingers, how they may be attached to one another, and moved about in space. In terms of physical affordances, the surface of an interactive artefact is one of the main resources for users to identify what physical manipulations to perform on the device. Surface appearance and materiality can invite the user to touch, move, or act upon the device in a certain way, and this can change substantially according to the choice of materials. Simply placing an electronic device in a new physical casing thereby affects what users will do with it and how they will treat it, as illustrated previously (Jacobsson, Fernaeus, & Tieben, 2010). Replacing a hard plastic surface with one made of soft materials, would invite for a different handling of the device. Similarly, an object with a rubber or hard plastic casing may be perceived of as more waterproof or robust than one covered in a soft fabric, wood or leather, and this would affect the way the object will be treated or interacted with. The physical manipulations an interactive artefact invites for are also highly dependent on the way the artefact has been made, for example how it has been assembled, or on the surface materials of which it consists.

Example: Textile as surface material

The properties of textiles or other soft materials such as knitted yarns, in combination with their crafting properties, meaning the ways in which they can be given form, can be used for designing particular types of manipulations that could be performed with an interactive artefact. The *Speaker Scarf* depicted in Figure 2a, which is a portable speaker re-designed as a scarf, is an example from our own design research that illustrates how using textiles or other soft materials as surface materials of an interactive or electronic artefact can be a way to design for particular physical manipulations with the artefact. It consists of a fabric speaker, a circuit board, and a switch on/off switch made of conductive and resistive e-textile materials, which is also used to adjust the volume (Figure 2b). Using textile in the form of knitted wool as the surface material of this speaker directed and restricted the design work, resulting in a final form that affords and invites for certain physical manipulation. The Speaker Scarf can be worn around the neck instead of placed on a table surface, inviting for intimate and personal interaction with the speaker. The textile speaker component is small enough to be held inside the palm, and has to be brought close to the ear, when the scarf is worn. This creates a personal experience of listening to music. Additionally, the physical manipulations that need to be performed, when switching on or off the speaker or when adjusting the volume of the music, have been directed by the use of soft materials for designing the speaker. In order to switch the speaker on or off a metallic button has to be inserted in a loop made of resistive yarn, and similarly, by inserting the metallic button in one of the other loops, the volume can be adjusted.

Fig 2. The use of textile and soft materials guided the way the *Speaker Scarf* has been designed, in particular the specific physical manipulations that need to be performed in order to listen to the music. Left: the textile speaker unit and the on/off switch that can be also used for adjusting the volume. Right: Adjusting the volume by placing a metallic button on one of the loops made of resistive yarn.

Interactive Behavior

How the surface can support users to interact with an artefact also depends on the particular inherent properties of the surface materials, for example their abilities to conduct, to resist, or trigger. As a resource for supporting digitally mediated actions or physical manipulation, the design of a physical surface plays a central role in providing particular possibilities for interaction. The physical surface can influence how media content may be manipulated or navigated, for example suggesting possible ways of accessing recorded data, but it can also evoke subtle interactive qualities. It is on the surface that we learn how physical buttons, speech, or gesture recognition software may work as direct controls to actions that a device may perform. The physical surface may for instance indicate how to handle and press buttons, but even when the surface is not responsive as such, its form factors still indicate how the device could be held and manipulated in the engagement with internal sensors, such as accelerometers.

Example: Copper, silver, wood and textile as surface materials

Different types of materials can have very varied ways in which they can be interacted with, and this can affect and direct the experience of interaction. Textiles and soft materials invite for actions of stretching, pulling or squeezing, due to their flexible and soft properties. This is often utilized for making input sensors that can be activated by stretching (Figure 4a), squeezing, rubbing or stroking which would not be possible with other materials that are hard, such as plastic composites, wood or metal. On the other hand, the conductive properties of metals can be used for making buttons or switches by integrating metals such as copper or silver on the surface of artefacts and utilizing the resistive properties of bare skin, as described in (Tsaknaki, Fernaeus, & Jonsson, 2015). In Figure 4b are depicted three versions of simple buttons made of copper, silver and wood, which are utilizing that particular property of metals being conductive, in order to be triggered. This could not have been possible to achieve with other types of materials, such as leather or wood that are not conductive. Another example is wood, which affords to be stacked on blocks for example, and can be used for making sturdy and flat surfaces that can be easily manipulated and interacted with, when used as a surface material on interactive artefacts. One of our master's students at KTH Royal Institute of Technology, John Brynte Turesson, explored wood as a surface material of interactive wearables. In Figures 4c and 4d, laser cut wood has been stacked in blocks and used to make input controls for necklaces that can be triggered when pushed vertically, or slided on two directions. In general, making use of the properties of craft materials can be a way of using those materials for performing the actual interactions, such as pulling, touching, rubbing, stretching, rather than only as surface materials or casings, to protect the electronic components hosted under the surface of an artefact. In that way, surface materials and casings may have the potential of taking a more active role in the interactive behavior of an artefact, which can dynamically influence the experiential properties of an artefact more broadly.

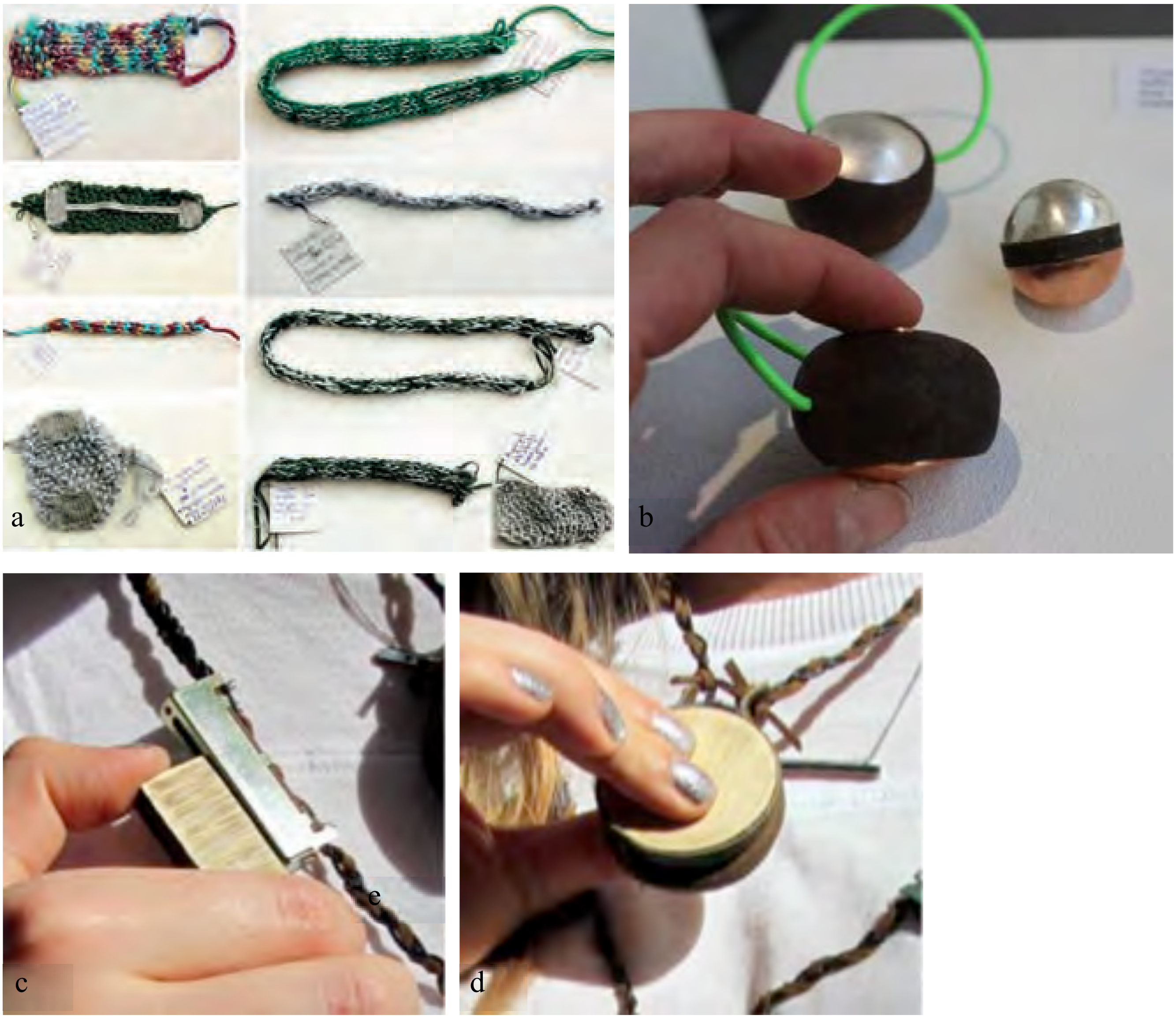

Fig 4. The unique properties of craft materials, based on their abilities to conduct, to resist, or trigger can influence the interactive qualities of an artefact, when used on its surface: a) Input stretch sensors made of conductive and resistive yarns, and textiles, b) Three versions of buttons made of copper, silver and wood. The conductive properties of metals can be used for triggering a button with bare skin, c) and d) Stacked wood has been used on the surface of a potentiometer and a button, due to its property of being sturdy and robust.

Discussion

It may seem redundant to explore artefacts in terms of their individual constituting parts, as in the case with surface materials of interactive artefacts, especially when these parts do not *do* anything actively. However, by presenting simple examples we have shown how the mere perceptual features of objects, or a seemingly ‘dead’ surface appearance sometimes becomes an important resource that can guide the interaction with an interactive artefact, in a very concrete way. Especially craft materials, which are the focus of this paper, when used for designing interactive artefacts can contribute to the experience of interaction, due to of their physical perceivable properties, or more unique attributes in regards to the crafting or fabrication techniques that can allow or the different forms they can take. We want to acknowledge however that we have only given very few illustrative examples and that exploring more broadly the experiential properties craft materials can provide when used for designing interactive artefacts is a space that demands further studies.

The aim of this paper was to present how the use of craft materials on the surface of interactive artefacts provide very particular experiential properties in interaction. Even though this analysis reads as a meta-reflection of already designed interactive artefacts rather than a concrete suggestion of how to make use of those experiential properties in a design process, we believe that by highlighting the three properties of craft materials, sensory experience, physical manipulation and interactive behaviour, others can benefit from that and even use them in a design process. If designing a wooden surface that responds to touch, for example, by unpacking the three experiential properties during the design process, would help in bringing forth what is particular about wood and how its properties can be best utilized for interacting with the surface, and consequently with the artefact.

Reflecting on the three categories of experiential properties presented above, it becomes obvious that they are overlapping to a great extent and a clear distinction between the three would be difficult to make. For instance, we presented the experience of interacting with the leather pressure-sensitive surface of the sound box as a sensory experience in regards to the very particular tactile properties of leather. But it could as well be described from a perspective of what types of physical manipulations leather invites for, in regards to the crafting affordances of leather and how that would influence the physical manipulations with an interactive artefact, when leather would be used as a surface material. Similarly, the Speaker Scarf has been discussed from a perspective of how the soft textile material used for giving form to the speaker directed the design of this artefact, especially in regards to how the speaker can be physically manipulated. But at the same time, the textile material being soft and warm provides a very particular sensory experience while listening to music that other, more common materials used for designing a mobile speaker, such as plastic composites, do not provide.

A particular aspect that we would like to draw attention to is that designing interactive artefacts with craft materials on their surface, apart from provoking reflections on the notions of craft more broadly, might shift the way those artefacts will be taken care of. Designing the surface appearance of an artefact involves, apart from supporting particular interactions with it, how actions such as repair, maintenance, modifications or recycling could be supported. Caretaking includes possible ways of changing or charging the batteries, switching the device on and off, how it can be cleaned or how it may be physically moved and stored, among others. Including materials such as wood, leather or metal in a design may facilitate caretaking, as observed in practices of traditional crafting in which materials such as leather, wood or precious metals were involved (Rosner & Taylor, 2011; Tsaknaki et al., 2015). A crafts approach on the design of interactive artefacts can also highlight the impermanent nature of interactive technologies, being fragile and short-lived, and possibly confronting this reality, as described by Tsaknaki and Fernaeus (2016).

Verbeek (2010) discussed that apart from robust designs, another way of extending the life span of a product would be to attack cultural factors that make products abandoned long before they become technically worn out. Based on this idea, the cultural links and values that exist to objects made of craft materials such as leather or textile may be transferred to electronic products, when such materials are integrated in their design and thus contribute with new meanings or increase their value, and therefore their longevity. This is even more interesting when looking at the potential of combining so-called traditional crafts with high-tech tools, materials and design processes. If artefacts would be designed in the intersection of textile handicraft, mechatronics and interaction design, or silversmith crafting and interaction design what particular meanings and values such artefacts may carry and reflect? But also how would such hybrid artefacts influence the practices that will emerge around them, in relation to the social and cultural context in which they will exist?

The above questions point to the fact that artefacts and consequently surfaces are part of a social and cultural context rather detached from it, and should be studied as such. We find this to be a highly important aspect, since it is when an interactive artefact is contextually situated that its features may be used as an indicator of the current state of activity, as a resource for attracting people's attention or for personally reflecting on, or engaging with it. Giaccardi and Karana (2015) stress the importance of situating artefacts socially and culturally, in relation to people and practices, which consists the performative level of their framework. Similarly, Fernaeus et al. (2008) in their action-centric view on tangible interaction discuss that referential, social and contextually oriented action is one way that a tangible artefact may work as a resource for action. The reason why we did not include this aspect in our analysis of the use of craft materials in interactive artefacts is because we wanted to focus on the inherent and craft properties of specific craft materials, reflected on the illustrative design cases we provided. Those hybrid artefacts have been designed with a focus on materials and making, instead of addressing particular use contexts. However, we are planning to expand on how craft materials used as surface materials of interactive artefacts influence the interaction, when placed on a social and cultural context of everyday use practices.

Additionally, studying surfaces in context and in relation to the passing of time can reveal new aspects in regards to how a surface can concretely influence the interaction, since the different forms a material surface can take, deliberately or unintentionally, play a significant role in how the artefact will be experienced during its lifespan. In particular, the ways in which craft materials change over time, play a significant role in how such materials, being on the surface of artefacts will affect the context of use but also interactions and relationships that may emerge between the artefact and potential users, as discussed by (Giaccardi et al., 2014; Robbins et al., 2016; Rosner, Ikemiya, Kim, & Koch, 2013). As mentioned by Verbeek and Kockelkoren (1998*,* p. 30) "some materials, such as leather, may also become more beautiful when used for some time, whereas a shiny, polished chromium surface starts to look worn out with the first scratch". Signs of aging developed on a material surface can take the form of traces, patina, cracks or change of color among others. In that way, wear and tear alters the tactile and visual properties of a surface, and such signs could be perceived and interpreted in a variety of ways. For example, the patina that materials such as copper, silver, leather or wood develop on their surface over time could be used for creating patterns of interaction and use, or as a visual element to reflect upon usage, signifying for example areas or buttons that have been 'pushed', or 'touched' more than others (Tsaknaki et al., 2014).

Conclusion

In this paper we looked at the surface of interactive artefacts, and we focused on the experiential properties of surfaces, which even though they do not 'do' anything actively, are still a very central part of how an interactive artefact is experienced, and physically interacted with. Specifically, we looked at how the craft materials leather, wood, textile and metal, when used as surface materials of interactive artefacts can influence the experiential properties of interaction in regards to sensory experience physical manipulation and interactive behaviour. Concluding, we believe that the way an interactive artefact is experienced is not only a question of what is displayed on its surface or how it functions. It is also important to consider how the artefact as a whole is made sense of in active engagements by people, based on personal experiences, expectations but also on the surface materials that are the 'mediators' between the artefact and the surrounding context. Physical surfaces are a rather important feature for interaction designers to actively work with, and deserve further studies in this domain.

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Uncovering Digital Craft Methods in the Design of Enhanced Objects and Surfaces

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Abstract

This paper focuses on the growing field of creative practice that aligns physical and digital spaces, processes and experiences. This field recognises the potential for heightening human expression and sensibility through practice that engages multi-disciplinary, hybrid approaches taken from computing, engineering, e-textiles, craft and design. Craft practice is explored within a broader field of making, which in this research, is applied to the design of responsive objects in a move towards more nuanced, empathetic interfaces.

The situated body is central to comprehending the nature of experience, as we perceive the world through multiple sensory modes. Key commentators have framed an engagement with felt human life, leveraging its expression as a vehicle for enhanced relations with technology. Our physical sensorium is mirrored in the apparatus of technological systems that utilise artificial sensing, affective or cognitive schemas, and are a central influence on the development of embodied technological practices.

Undertaking a making practice generates artefacts, which respond to these contexts. Firsthand involvement in a hybrid making practice by the researcher builds a rich body of work that contributes experience and tacit knowledge of digital craft principles. Textile structures are combined with computational capability to create micro, self-contained control systems that afford temporal, interactive form.

Collaborative strategies and co-creation are central to the practice, sharing ideas, material contributions and dialogue during making processes. Methods evolve as a continual negotiation between intention, action and impulse revealing practice as a series of interconnected relationships that move between disciplines, contributors and skill.

Introduction

Alignments between the tactile properties of physical materials, integrating them with the intangible structures of digital technology are implicated in more nuanced, multi-sensorial encounters with technology. The human-centred design specialist Daniela Rosner states, *"digital and non-digital materials are equal partners in practice"* (2012, p. 321). Anna Vallgårda, interaction design proferssor, describes the production of computational composites, form-giving practices that perceive of digital forms as materials for design, with their own unique properties (2013).

The exploratory integration of digital capability within creative projects has increased. The practice of e-textiles, also known as electronic textiles, enables electronic components and small computers to be embedded within fabric and textile surfaces. These practices, reliant on open-source, computing and electronics platforms have come to exert significant influence on the development of physical computing. Communities of practice have evolved around micro-processor use, particularly the LilyPad Arduino, a sewable, e-textile hardware kit developed by Leah Beuchley (Buechley & Hill, 2010). Adopted initially by designers and engineers, easy access and low-cost have resulted in the generation of small, niche communities, including higher proportions of women, amateurs and hobbyists.

Principles of craft bind these practices together by promoting experimentation as critical to the process. Craft ensures that digital practices, whether they focus on material, informational, temporal or interactive forms can be approached, not only in a rational manner but as design theorists Jesper Simonsen and Toni Robertson (2013) express, as subject to human agency, the creation of meaning and the primacy of human experience. Rosner et. al (2015) discuss hybrid craft, the confluence between traditional modes of craft activity and computational resources. This confluence, they feel, "might lead to new understandings of expressivity, skill and value." (2015, p. 1)

Affordances of touch, sensation and meaning encountered through material forms have been leveraged to create work that aligns with digital potential. *Felted Terrain* (Lim, 2013), a sensory form exhibiting behaviour in response to natural physical gestures such as stroking, pressing and cupping demonstrates the crafting of computational elements into the design of the piece. Approached as yet another material in the design and making process, the sensory experience of touching the felted material communicates a textural sensibility, making textile and touch, a *"particularly potent vehicle for both cultural and artistic expression"* (Bristow, 2012, p. 45).

Much creative design research and technological practices lean on the theoretical propositions of pragmatism. The primacy of action, out of which theory grows, denotes practice as central to all creative activities. In this research, practice is foregrounded as the focal methodology, the primary means of making, discovering, articulating and evaluating insights, ensuring they can be experienced through crafted means. Estelle Barrett expands on the situation of practice *“being in-the-game where strategies are not pre-determined, but emerge and operate according to specific demands of action and movement in time”* (Barrett & Bolt, 2010, p. 4).

The works described engage in digital craft practice, examples of production that rely on relational knowledge, using fabrication methods and processes taken from a range of disciplines. Reflecting on practice experiments highlights themes, interests and crossovers that signpost how digital craft can be implicated in more nuanced, felt material experiences to contribute a perception of value in digital craft practice. Insights taken from reflection on the pieces are summarised and rearticulated as methods and intentions, key criteria that shape thinking on future goals and practice.

Design criteria focus the development of methods, creating common threads that connect relevant categories and frames the practice. Consideration of these methods helps evaluate the creative and experiential expressions of the work, using these evaluations to guide revised pieces, iterations that respond to insights. The type of questions, the responses, their quality and resonance to the practice, are essential to understanding how you explore multiple concepts simultaneously to articulate an overarching methodological contribution. As the craft theorist Glenn Adamson (2013) explains, the practice addresses post-disciplinary practices to create its own tactics of making, the boundaries of which are open and fluid, negotiating a path that moves between disciplines, authors, skill and process.

The Practice Pieces

Touchplay

The production of *Touchplay* provided insight into crafting soft interfaces designed to encourage tangible interaction and play, designing the form of interaction and reflecting on how it unfolds in relation to use and operation. Constructed using digital embroidery techniques, discs behave as input elements to sound. Enhanced with conductive thread disc movement and position can be detected via a microcontroller to enable interactive potentials. *Touchplay* explores the tactics of making from a digital craft perspective to highlight a material focus on form generation.

Figure 1: Touchplay by Lucie Hernandez, uses digital stitch, copper and conductive thread to create sound responses through touch.

Touchplay is an example of a computational composite, an experiment in process, demonstrating how material and immaterial forms can be conceived in conjunction, combined through craft processes, and responded to by others. Engaging participants in a work is critical to determining its expressive qualities and potential through their responses. Natural affordances and the tactility of material forms are exploited to invite participation and explore weight, texture and form. It is an enquiry into physically constructing an object that responds to the capabilities of the body and the senses. As stated by Erica Robles, and Mikael Wiberg in *Texturing the 'Material Turn' in Interaction Design*, "Texture refers to 'the feel, appearance, or consistency of a surface.' The emphasis on the experience of a surface resonates with contemporary phenomenological understandings of the user interface in the area of HCI" (Robles & Wiberg, 2010, p. 3).

Practitioners in the field of interaction design offer frameworks for approaching an integrative practice that span multiple domains of making. Anna Vallgårda (2013) outlines compositional design in which form-giving practices specialise in *"how to craft the computational material's temporal form in combination with physical forms and interaction gestalts".* (2013, p. 1) She stresses that it is not just the formal aspects of computational composites that designers should become familiar with but they should become mindful of the *"new expressions they afford"*. (Vallgårda, 2013)

Textile practitioner Maxine Bristow (2012) asserts the significance of the material dimension by highlighting the ability of objects to bear witness to our everyday lives. Witnessing our lives, our actions and thoughts is akin to perception. Objects bear witness through their presence in the world, being contingent to events, operating through us by contributing to our actions. Through our perception of their contingency, we come to know. These insights suggest that through perception, meaning arises, a significance, which the objects and our relationship to them initiate. Objects don't perceive, they are inanimate, but they can, in Bristow's words *"provide us with convincing testimony"* (2012, p. 45) that reveals the significance of our relationships and the qualities they enact.

Touchplay II

Processes around making, testing and embedding interactive capability are critical to revealing emergent sensibilities within the work, which in turn contribute to insights and further revisions. On-going cycles of reflection and iteration are inherent to the process and important methods in this practice. A more recent version of the previous piece, *Touchplay II*, adopted felt to create a more textured surface with added dimensionality that invites touch and promotes pressing. This suggests that pressing and texture are component elements that direct action, linking pressure with its role in sensory stimulation, facilitating and determining affect.

Figure 2: Touchplay II, by Lucie Hernandez

Critical questions around craft practice demonstrate the relationship between original intentions and impulsive processes undertaken in pursuit of an outcome. Play, synthesis and discovery modify and invert intention through discovery and material resonances that affirm how design and craft interrelate.

In the pursuit of digital craft research I am engaged in, not just creating the work, but also understanding what is going on beneath the surface with regard to emotion, affect, and being mindful of those expressions that materialise out of designing experiences that engage with people through technology.

Reflection on my own investigations reveals a "*self-reflexive mapping"* (Barrett & Bolt, 2010, p. 5) and intuitive decision-making during the creative process, demonstrated by improvisational approaches to creative decisions. Being in tune to experiential expressions maps the investigation onto a different set of theoretical principles. Serendipitous choices and random decisions were in fact a *"playful response to a structure"* (McCullough M. , 1998) that referenced original intentions even as these shifted and evolved.

Crafting a Hybrid Material Practice

Craft explores the properties of material behaviour, its texture, dimensionality and instrumentality across physical and digital forms. Articulating a personal, material vocabulary engages textile, thread, fibre and wire to build fabric structures, substrates and membranes to extend and support digital integrations and capability. Deep engagement with materials requires developing a sensibility to those qualities that create felt sensation in participant users. Craft approaches integrate indeterminacy into the process of making, balancing intentions and impulses that adjust during a material dialogue. A digital craft practice is formed of a hybrid materiality to align notions of the physical with the digital. I locate craft practice as a continuously evolving, fluid space that expands into multiple domains of making. This approach engages with digital practices, incorporating physical material and immaterial form, structure and information.

Adamson (2013) stresses that the key to understanding craft, is to view it as an approach to making, a mode of form production that focuses on deep engagement with the materials and processes required for creative action. Risk is deeply embedded in the process, which craft practitioner David Pye asserts is "*any kind of technique or apparatus in which the quality of the result is not predetermined, but depends on the judgment, dexterity and care which the maker exercises*" (2007, p. 20).

My work defines methods for acting in and through my chosen materials, understanding their affordances and tangible/intangible properties in alliance with my judgment and intuition. This material enquiry builds tacit knowledge around material form, behaviour, texture and constraint, influencing corresponding choices around selecting media and technologies. As a maker you are in dialogue with materials to articulate and shape form, a process that Tim Ingold describes as 'correspondence' (Ingold, 2013). This language of material knowing emerges through craft practice. Deep familiarity and knowledge around material forms is arrived at through habitual, methodical working and engaged practice. Also referred to as 'know-how', we arrive at personal knowing through bodily engagement with tools, materials and technique. As Ingold says, it is clear that the way to know occurs in the act of making itself (Ingold, 2013). Drawing together the elements of practice yields understanding, and is the place where we articulate material knowledge.

Exploring the Physical sensorium

Understanding the physical sensorium and its situated relationship to objects, materials and the environment is central to the efficacy of this practice. This relational perception of stimuli, through our senses implicates the body as referent, actuator and site requiring its intervention through dialogue and response. By coupling computation to physical objects the research extends the evocative possibilities experienced and perceived through our bodies. Sensory perceptions, embedded within situated relationships, require further evaluation to determine the extent to which they are triggered in response to material correspondences. Methods are being developed to further understand the role of the senses, especially touch as a means of experiencing a tactile material mode that can be coupled with other sensory modes to contribute to felt expression and sensibilities.

Social computing theorists, John McCarthy and Peter Wright explain the centrality of human experience in understanding our engagement with technology. They stress the emotional impact of action in our lives and extend the word experience to the *feltness* of life for us (Technology as Experience, 2004). In formulating an approach to pragmatic thinking McCarthy and Wright draw attention to *"the idea of ordinary, everyday experience of being and acting in the world"* (2004). The pragmatist approach views experience as crucial to understanding how we make sense of reality. If we are to understand the nature of experience we must engage with felt human life and use it as a vehicle for enhanced relations with technology.

The paper, '*The experience of enchantment in human–computer interaction'* develops a conceptual framework for design and analysis in which affective, felt experiences with technology are prioritized. This approach embeds these ideas and concepts in descriptions of experiences with technology, which examine enchantment and emotion. "An object or interactive system that is likely to evoke enchantment should offer the potential for the unexpected, give the chance of new discoveries, and provide a range of possibilities" (McCarthy, Wright, Wallace, & Dearden, 2006).

Designing Multi-sensory Experiences

Concentrating on those aspects of experience relevant to this research requires viewing experience as relational, constituted of objects, people and events that connect and interact. Within these dynamic situations, each of the constituent elements plays a part in shaping our conception and understanding of the world. The field of Material Culture studies the senses, perception and multi-sensory modes, particularly their role in meaning construction. Material Culture in Action, a conference at Glasgow School of Art, aims to *"expose the powerful interrelationship of the physical sensorium to a relational understanding of the world"* (Roy, 2014). The body is implicated as site for these understandings to unfold in enactments with contingent, provisional and relational phenomena.

We engage in the world around us through sense perceptions, providing us with the means to participate and interpret experiences. Multi-sensory responses perceive the contingency of objects in social situations. As material culture explores, alongside anthropology, sociology and psychoanalytic theory, objects are deeply embedded in the social and physical situations in which we exist. In this sense, as Bristow describes, objects are involved in the *"objectification of social relations"* (2012, p. 46). The implications of this assign meaning in our response to objects, based on our direct or indirect multi-sensorial engagement with them.

Subjective processes of meaning construction need to be understood in relation to everyday reality. In *Distributed Creativity* (2014), Vlad Glaveanu explains how the nature of cognition is shifted from inside one's head to the world around us. The concept demonstrates that thinking and cognition are contingent on situations and experiences in which each human subject is deeply embedded. The senses play a key role in helping make sense of environmental phenomena to demonstrate connections and affirm the significance and meaning of action. Malcolm McCullough, in *Digital Ground*, provides us with proof of the centrality of the human body to action, sensing, cognition and understanding, *"the body imposes a schema on space"* (2004, p. 28).

Interaction and Engagement

Designing interaction can be identified as intrinsic component to working digitally, reflecting the dynamic temporal nature of computational composites. Anna Vallgårda (2013) outlines the computer's ability to change between states, demonstrating a practice that specialises in how to craft the computational material's temporal form in combination with physical forms and interaction gestalts. This research shapes the form of interaction through the physical, setting up a tangible interface that encodes usage and stimulates response. Designing and interpreting interaction and its role in contributing affect through the work are closely connected to participant experience. This approach ensures temporal state changes are thoroughly considered to discern their influence on participant engagement and the emergence of felt sensation. Additional methods aim to evaluate how less deterministic, more open, personal interaction can engage fuller emotional responses through the physical sensorium.

Shaping the interactive capabilities of the practice pieces produces sensory expressions in participants through their actions. By coupling computation to physical objects the practice extends the evocative possibilities experienced and perceived through our bodies. In *Design Research* (2003) Brenda Laurel considers how "delight" can be a designed response and links to *"the pleasure offered by an object that richly engages the senses"* (Laurel, 2003, p. 316). Expressions and emotional responses are a constitutive part of the experience, a result of embodied practices unfolding in the world contributing expressions of delight, playfulness and meaning.

Authorship in a Post Disciplinary Environment

Describing authorship in a post disciplinary environment entails reviewing the conditions of making, the sites and forms of labour. In this context, artefact creation is viewed as a composite, an aggregate object constituted of labour and skill arising from various, distributed production sites.

The visual arts critic, John Roberts, details contributions to artefact creation describing a mode of authorship typical of post disciplinary practice in which the maker may or may not even touch the object of his creation (2008). Works produced in this manner might leverage the *"**attached** hand of the artist and the **attached** hands of non-studio labour…and the **detached** hand of the artist in its role as executor."* (Roberts, 2008, p. 155). Focusing on how authorship is related to actual systems, economic, technological and social networks, implicates the maker in a swirling space of forces and their interrelation, overlap and influence. According to the architects Eric Höweler and Meejin Yoon, cultural production has become *"a space of dialogue, and a space of plural and co-implicated agency"* (2009, p. 11).

The post disciplinary practitioner is engaged in a series of activities that leverage contemporary design and production techniques alongside technological practices to create objects, surfaces or environments. Approaches may extend to harnessing craft processes, the skill of other practitioners and network capabilities, which are increasingly relied upon to open up spaces for distribution, learning and media production. Knowledge production is relational and the hybrid connections and links between categories of making that practitioners create are critical aspects of their practice and resulting work (Doucet & Janssens, 2011). Adamson (2013) describes this move towards inventing a whole new mode of production, working like a producer, going beyond the act of creating a work to facilitate, coordinate and reconfigure the tactics and skills of making.

Analysis of the work described above demonstrates that the labour and skill required in the production of the pieces, transcends individuals to integrate collaboration and multi skill production from other makers, technologists, programmers and designers. Individual agency is condensed to form a series of enactments with others. Craft practice is able to act and exist within this plural, collaborative zone to appropriate tactics of making that are, according to Adamson *"increasingly intermingled and hybridised"* (2013).

Conclusion

This practice-based research contributes to the field of e-textiles, digital craft and interaction design by revealing methods, techniques and processes that contribute to more heightened sensibilities and evocations from outcomes that engage in nuanced, tactile, sensual approaches to making. Combinations of physical and digital forms produced from experimental e-textile and computational compositions, evoke enhanced sensory engagement. This reveals methods that articulate the temporal, material and interactive elements of crafting augmented, physical objects to heighten the evocative, meaningful experiences perceived through our bodies. A confluence between material and digital capabilities in the practice outcomes guide participant sensibilities to new understandings of expressivity and felt sensation through play, discovery and curiosity, manifested through tactile engagement with physical forms to blend sense modalities while foregrounding the sense of touch. Its contours are open, emergent, responsive and experimental in its relationship with, through and to material contexts, a variety of human and non-human actors and situated concerns. The process involves blending open and closed approaches to prototype development as ideas and forms cohere into artefacts only to fracture and open up for additional reflection and revision through interaction and use. Consolidation of these insights through further experiments and practical engagement will evaluate participant response to the work and map meanings and affective significance.

This paper acknowledges the relevance of post-disciplinary practices to artefact creation, while also highlighting the blend between craft and design approaches. These developments combine with embodied, tangible interactive forms to demonstrate that computer science perspectives and practices are embracing physical, material explorations in designing human-computer interfaces. Creative interventions from practitioners working across disciplinary boundaries suggest that outcomes should privilege the body, senses and human experience for more nuanced engagements with technology. This is the landscape in which a digital craft practice can flourish, which doesn't separate making and experiencing but reveals the affinities between each and the necessity for crafting the expressions that emerge.

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Signals as Material: From Knitting Sensors to Sensory Knits

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Abstract

The aesthetics and design are often given less attention when developing smart textile sensors and applications. On the other hand, in constructive design research, the designer is inherently getting closer to the technology. To fully utilise the expertise of a textile designer and to bridge this gap between engineering and design, an understanding of both the smart material and its implications is needed. Thus, there is a need to augment the methods available for a textile designer to develop smart textiles. To this end, we created a set of knitted sensory samples, providing a basic set of structures for the evaluation of the signals towards a visual method for evaluating their qualities. From an engineer point of view, the samples focus on conductivity, capacitive coupling and impedance changes, and from a designer point of view, vary in the type of electroconductive material, knit patterns and the visual differences. The samples were evaluated using Lissajous-figures, which provide an unambiguous representation of the frequency-related behaviour, being relatively straightforward to utilise. The measured differences were often clear, with structure- and fibre-based differences being made visible through the use of variable frequency. Our approach focuses on the strengths of both designers and engineers, by providing a visual method satisfying both experiential and technological requirements, as well as giving a tool for communicating about the behaviour of the smart textiles.

Keywords

Knitting; Smart Textiles; Method; Lissajous figure; Constructive Design Research

Knitting, as a construction method for textile-based products has a long history in practice. More recently, knitting has also been used as a basis for smart textile applications. Although knitted textiles branch into fields of art, craft, design, engineering and science (Glazzard, 2014), smart knit applications, akin to smart textiles in general, tend to apply a technological-led approach. On the other hand, designers are increasingly involved in the technical construction of artefacts (Koskinen, Zimmerman, Binder, Redström, & Wensveen, 2011). Since the designers are involved in the creation of smart textiles, their design methodology needs to be augmented, as the technological aspects are typically outside their spectrum.

We quote '*Thus, when a decision is to be made on the materials to be used in a new design, competence is needed in predicting and defining both the experiential qualities and the performance qualities of materials*' (Karana, Pedgley, & Rognoli, 2014, Introduction).

Smart textiles are a broad field, which invariably covers technological, material and experiential aspects in the design process. Previous design research has presented an insight into conceptual and pragmatic methodological tools for designing smart textiles, such as open source learning with step-by-step tutorials(Perner-Wilson, 2011; Kobant DIY), and some in the form of co-developed examples (Swatchbook, Hertenberg,2014).

Textile design methods have been augmented, such as to design for dynamic patterns (Worbin, 2010), and with a recipe-based method and pedagogical tool for colour change with thermochromic ink (Kooroshnia, 2015). There is also a methodological framework derived from architectural design, interaction design and textile design for interactive textile design in a space design context (Dumitrescu, 2013). Smart textiles can also be used as raw materials for Design (Dumitrescu, Nilsson, Persson, & Worbin, 2014), and as research probes (Baurley, Brock, Geelhoed & Moore, 2007). The act of smart textile development, as well as the objects, has been used in participatory design process (Briggs-Goode, Glazzard, Walker, Kettley, Heinzel & Lucas, 2016).

In some of these examples the work process saw developmental iteration and exploration, as the methods were not developed enough towards the design-oriented utilisation of electronic signals. It should be noted, that a considerable number of *all* smart textiles use electric signals in one form or another. However from our perspective, technological aspects such as material properties and electrical properties are equal in importance to aesthetic and experiential aspects. Specifically, we focus on the properties of the electrical signal itself as an equal material in the design, having implications for both textile and fashion design.

As there seems to be a lack of designerly methods suitable for independent evaluation and development of textile structures for signalling and sensing, and while there are methods for engineers, there is a need for a bridging method that is agile, visual and adaptable to different purposes. At the same time, the method enables the designer to take a more independent role, allowing better utilisation of their skills for both aesthetic and technical purposes and acts as an additional tool for communication. More importantly, the purpose of the paper is not to provide a material library of knitted samples with different electronic signalling properties, but to validate the lissajous-method for supporting experiential aspects of textiles, without compromising technical design aspects.

Background

In order to provide a scope for the current aspects regarding sensor or application design, we look at knit and smart textile-based applications, technical approaches and implementations, with a focus on touch sensing and signalling. We also refer to other soft materials, however our main domain is with knitted structures, being versatile for smart clothing and smart textile applications due to the stretchability and thus wearability (Lam Po Tang, 2007: p.285).

One of the earliest uses for electroconductive yarn in 3D-knitting explored fundamental issues regarding practical implementation without any specific application (Power & Dias, 2003). However, one of the earliest fully knitted applications was WEALTHY, a wearable platform utilizing knitted piezoresistive sensors and stainless steel electrodes (Taccini, Dittmar, Loriga, Paradiso 2004). Since then, resistive knits have been utilized in a variety of contexts, such as a skin for a robot (Yoshikai, Fukushima, Hayashi, & Inaba, 2010) for a walking application (Cho, Jeong, Paik, Kwun, & Sung, 2011), to mathematically model knits, e.g. to measure respiration (Li, Yang, Song, Zhang, & Liu 2009) and elongation (Yang, Song, Zhang & Li, 2009).

While the resistive sensors have been thoroughly studied, by including capacitive and frequency-related aspects give a better understanding of the useful material properties. One such approach is to use knitting to create buttons, focusing on the changing impedance over frequency, and exploit those changes in an amplitude-based detection. However, the described circuit implementation focuses on the use of DC and resistance, as the resistance change in a frequency-based measurement did not provide good enough detection (Soleimani, 2008).

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Conversely to the previous studies, the development of unobtrusive sensors was a starting point in a research by Wijesiriwardana, Mitcham and Dias (2004). The paper described the use of knitted solenoids to achieve inductive coupling to measure the elbow angle, and explored the use of knitted EEG-electrodes. Additionally, knitted capacitive switches and strain sensors were briefly discussed. The knitted switches were explored later, with the capacitive sensor structure modelled and measured in a frequency domain, even though the actual sensor circuit intended for the capacitive knit would be using DC-current (Wijesiriwardana, Mitcham, Hurles, and Dias, 2005).

While not knit-based, there have been also research that complement the impedance and frequency-based aspects mentioned above. One good example is a soft capacitive grid-structure where the touching-points act as high-pass filters of different thresholds, for measuring larger surface areas, by using thusly attenuated sine-wave as the signal (Sergio, Manaresi, Tartagni, Guerrieri, & Canegallo, 2002). It clearly describes the differences caused by the soft textile structure used for filtering the sinusoidal wave, and discusses the signal change in an actively driven capacitive sensor structure.

Touch detection is a common and relatively vast application area in smart textiles that can be approached in different manner, and two papers focusing on the capacitive detection describe the different approaches. Soft capacitive fibres were used to create a touch sensitive matrix, using a frequency-based model and analysis (Gorgutsa, Gu & Skorobogatiy, 2011). The paper specifically models the impedance of capacitive touch sensitive areas, and bases the model of detection to it. It uses a signal source, a modifying soft structure and an analog measurement. However the phase differences and frequency-related changes, other than amplitude change, are not addressed. Another approach utilised a capacitive touch sensor IC with fabric strips on the sleeve (Randell, Anderson, Moore, & Baurley, 2005). Here an application specific IC was used with individual sensor strips, using a single electrode for the detection.

In the majority of these applications, aesthetics were not considered, or there was no significant contribution. However, while a few papers portrayed visual aspects of their applications, the visual appearance was merely used for providing information of technical data, i.e. the location of the capacitive fibres in a woven touchpad sensor (Gorgutsa, Gu & Skorobogatiy, 2011). Moreover, the actual implementation of the touch sensor was purely 'a proof of concept' of successfully integrating the fibre into a flexible textile medium, rather than discussing aesthetical qualities.

While not a comprehensive list, the papers point to the current dominating technology-led approach, which offers little emotional, expressive, aesthetical and sensorial fulfilment to the end-users. These factors are commonly exploited in fashion, clothing and interior textile-based products, which are all relevant factors for the commercial potential of smart textile-based products (Hwang, Chung, and Sanders, 2016).

Such factors have been explored in three full-fashion knitted garments (Tender, Vibe-ing, Well-Be), developed as demonstrators in the Smart Textile Services project (Kuusk, 2016). The garments were knitted to attach hard touch sensing and light or vibration components. Thus, the conductive yarn is described as means ‘for running power and information throughout the knitted garment’, while ‘showing the technical character of the garment to the viewer'.

In the music sleeve (Gowrishankar, Bredies & Chow, 2011), conductive yarns were used to enable on/off based textile interactions, and signalling, in a knitted user interface, however the aesthetic qualities were secondary to the functionality. Dumitrescu (2013) demonstrated in her doctoral research how technical and aesthetic considerations are implemented into the design of interactive knits, while ensuring that ‘the textile surface remains a design material and not just a functional interface’ (Dumitrescu 2010:20). The use of conductive yarn plays an active and immediate role in the design process. In terms of the electric signals, the purported use of the conductive yarns was important, however the detailed qualities of the signals were less so. They were utilised in elementary circuits and uses, such as for heating or as a switching element.

Thus, to broaden the utilisation of conductive yarns, and the pathway for a wider user acceptance, a better understanding over signalling aspects of smart textile design is needed. However, the signal needs to be considered from both engineering and design points of view.

Knit Samples

The knit structures

The knit samples were knitted with a combination of three different knit structures that were differentiated based on their functional purpose and named accordingly: 1) the primary knit structure, 2) the sensory knit structure and 3) the input electrode knit structure. The primary knit structure provided an overall structural foundation, while the sensory knit structure was the primary measurement area. The input-knit structure was used to feed the signal into the overall structure. All samples were knitted with Schoeller's Vision yarn, 50% Cotton, 50% Pan, Nm 30/3, while the sensory and input knit structure were constructed using electroconductive yarns.

The primary knit structure was constructed with the tubular jacquard structure (left notation in Figure 1). The knit structures of the 'sensory' area were formed of two primary stitch types, a knitted loop stitch (plain stitch) and a held loop stitch (float stitch) (Spencer, 2001) as depicted in Figure 2, where the correlating visual expression of knit surface with loop stitch types are shown with a close-up image of knit sample 3A_1B1. The stitch types alternated in different order according to the pattern in each pattern sections 1-5 and knitted into double bed structure. The structure of the basic form of the sensory knit is shown in the right notation in Figure 1. Alterations to the basic form of the sensory knit structure were based on variation in spacing between the plain and float stitch both in horizontal direction (course) and in vertical direction (wale), thus altering the density of the dotted lines. The input-knit structure employed either the basic sensory knit structure, or its variation, or, was knitted with a structure pattern consisting of full needle rib and plain, as seen in the centre notation in Figure 1.

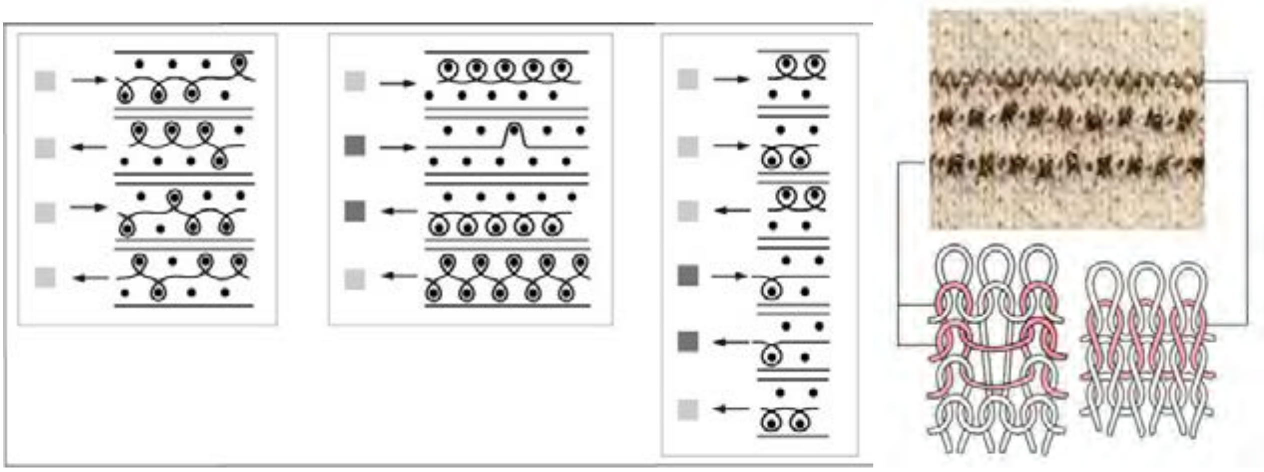


Fig 1. Left: Notation of tubular jacquard. Centre: Notation of input-knit in samples 3A-3E_1B1-4, 2B1-4, 3B1-4, 4A1-4 and 5A1-4. Right: Notation of the basic form of the sensory knit structure and of input electrode knit structure in samples 3A-E_1A1-4, 2A1-4 and 3A1-4.

Fig 2. Correlating visual expression of knit surface with loop stitch types. A close-up image of knit sample 3A_1B1 demonstrates the visual expressions of all three knit structures, while the structural drawing illustrates the yarn formation within the knit loop structures of two main stitch types. (Left) The back face of two loop stitches (float stitches) knitted on the front bed. (Right) The front face of knitted loop stiches (plain stitch).

The knit patterns

A total of five separate knit samples (namely as sample 3A-3E) were knitted that differed according to the conductive yarn used as follows:

1. Sample 3A: Shieldex 117/17 dtex 2-ply
2. Sample 3B: Karl Grimm High-Flex 3981 7x1 fach verselit Silber 14/ooo
3. Sample 3C: Karl Grimm High-Flex3981 7X1 Copper
4. Sample 3D: Karl Grimm High-Flex 3981 7x5 fach verselit Silber 14/ooo
5. Sample 3E: Bekaert Bekinox 50/2 Co 20% Bekinox 80%

Each knit sample consisted of five different patterns based on alteration of the stripes, which was furthermore based on variation of the repetition of the two stitch types discussed previously. Patterns 1-3 were knitted twice with identical sensory knit structure, whereas the input electrode knit structures differed; ‘A’ samples were knitted with one course of the sensory knit structure, while ‘B’ samples were knitted with the full needle rib and plain. Additionally, each pattern section was knitted four times extending the spacing (of one structural repeat) between the sensory knit pattern and input-knit (in each pattern (1-4)). In total, each sample was knitted with 32 pattern sections and coded accordingly, as seen in Figure 3. The designs provide alteration to the density of conductive pattern, hypothetically impacting on functional aspects of signal transmission, while simultaneously influencing visual and tactile expression.

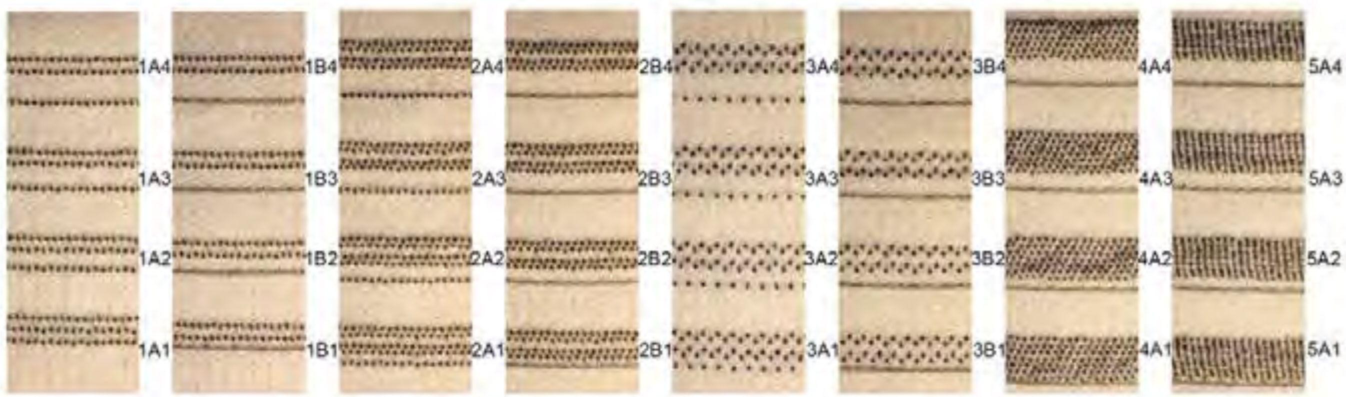


Fig 3. An exemplar of Sample 3A.The overall view of the coded 32 knitted pattern areas.

Methodology and The Measurement Setup

Every signal path or analog electronic component can be evaluated using a so-called blackbox model, where the component or the path is accepted to be treated as unknown. The behaviour of this blackbox is usually described and modelled using a transfer function, which is gained through experimentation, typically by feeding signals and measuring how the box has changed them. While the transfer function is typically represented by a complex function in s- (or frequency-) domain, it can be visualised for an approximate representation using Lissajous-figures (Kirby, Towill, & Baker, 1973).

Lissajous-figures (also called Bowditch-curve) are used to show the differences in phase and amplitude, however they were originally used with mechanical systems, for visualising tuning forks and mechanical oscillations (Lovering, 1881). As such, they are useful as being a visual indicator of the signal changes caused by the blackbox, which in this case is the textile material, the electroconductive fibres and the sensory area, such as knits for capacitive touch detection. The amplitudes and how they relate to the Lissajous-figure are shown in Figure 4.

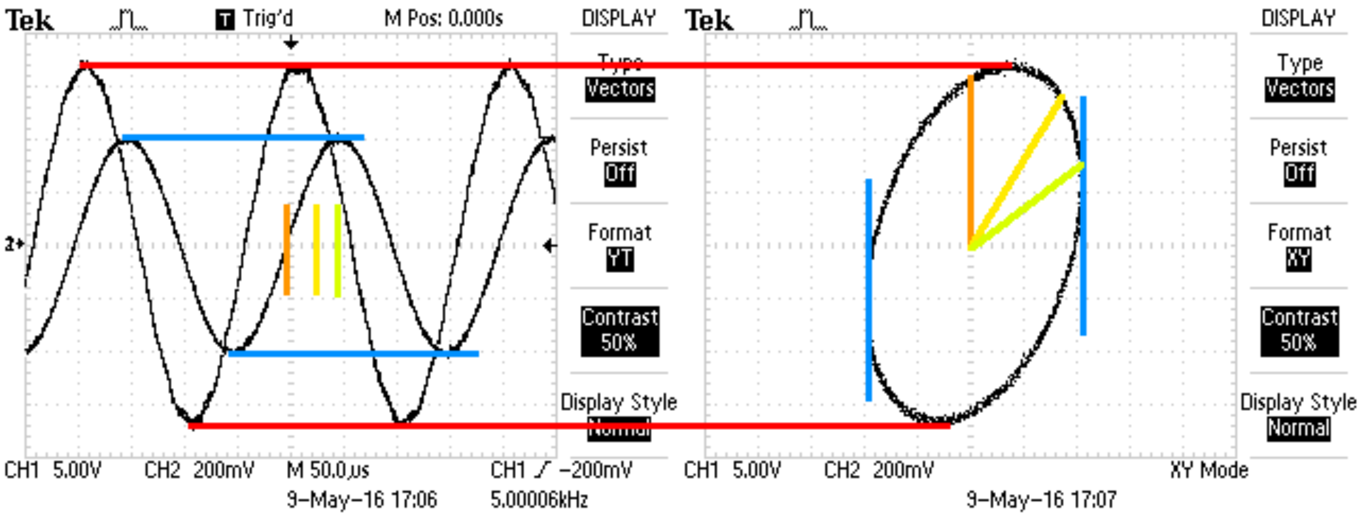


Fig 4. The standard signals (YT) (left), and the equivalent Lissajous-signal (XY-mode) (right).

If there is no change, i.e. the blackbox does not affect the signal in any way, the Lissajous-figure is shown as a straight line in 45° angle, with Y-values (output) matching the X-values (input), drawn in the middle of the oscilloscope screen. If the blackbox attenuates the signal, then the X-value remains unchanged, while the Y-value decreases, thus the straight line changes closer to the 90° angle. If there are any capacitive or inductive elements in the blackbox, the figure becomes more round. Semiconductive elements create irregular patterns.

The measurement setup requires an oscilloscope and a signal generator. Measuring the phase of a signal, and representing it as a Lissajous-figure using an oscilloscope, is well known (O'Shea, 1999). The textile patch is connected to both, and an additional load resistor of 470kΩ is used. (It is commonly available and less than 5% of the oscilloscope input probe resistance value, while still providing a suitable resistance to ground the electrode knit.) The input signal is a fixed amplitude sine wave, with the frequency being changed during the test. The setup, shown in Figure 5, is used to evaluate how and if the textile structure and the user input affect the signal, when using different frequencies. We fully acknowledge that the cabling and the signal termination are relevant, especially with higher frequencies. However, with lower frequencies those effects are less represented in the visual signal, and thus the Lissajous-figure can be used for estimating the behaviour of the signal in the textile.

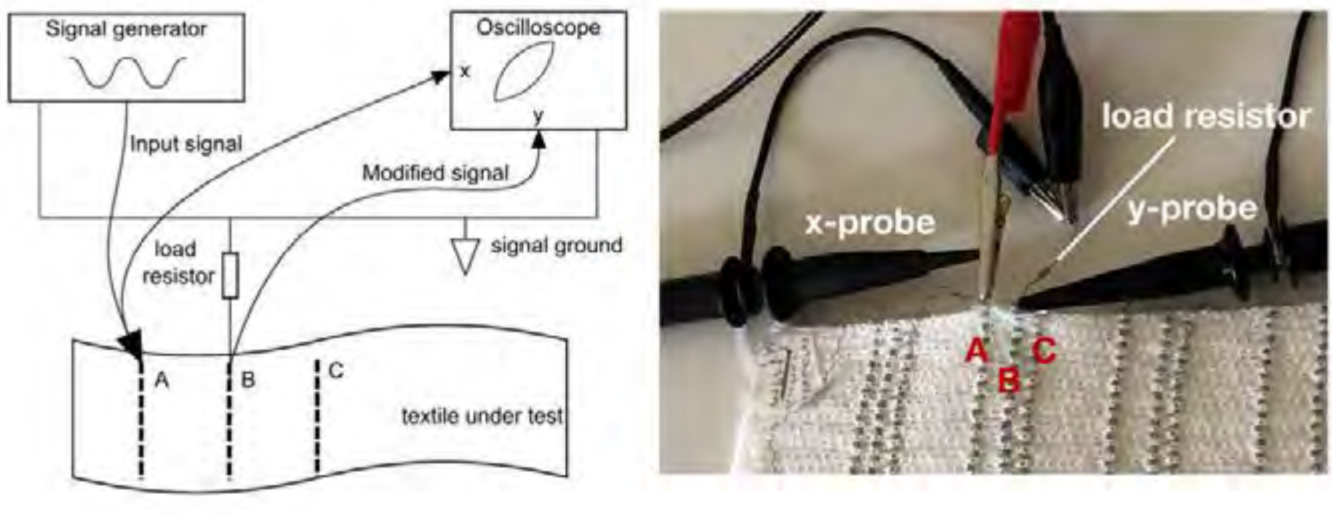


Fig 5. The measurement setup simplified (l), and the real setup (r). X-probe is connected to oscilloscope Channel 1, and the Y-probe is connected to oscilloscope Channel 2. B and C strips are connected together in the measurements.

How it was tested

The patterns were used to evaluate, if the method works, and if it is practical to use. In order to validate the method, three conditions were used to test the patterns. The first condition (OPEN) was with the samples as is, i.e. without connecting anything across the strips. The second condition (INSULATED) was by placing a well-insulated conductor on top of the strips being measured, in this case a 0,5l of water in a plastic container. The third condition (CLOSED) was short-circuiting the strips, by placing a well-conducting electroconductor on top of the strips. In practice, we used the same weight, however it had conductive copper tape, which was pressing on top of the textile.

OPEN is used to evaluate if there are any differences between the samples in general. The two extremes, OPEN and CLOSED would give the characteristics of the signal pathway. Thus, any purely resistive material being pressed or connected between the strips should be between the patterns of these extremes. If the Lissajous-figure is a straight line, the signal would not be influenced by the textile, for anything other than the attenuation. INSULATED was used to determine if the close proximity of a conductive material causes changes in the signal, such as when the knit is close to a body. However, we stress that INSULATED is not equivalent to skin contact.

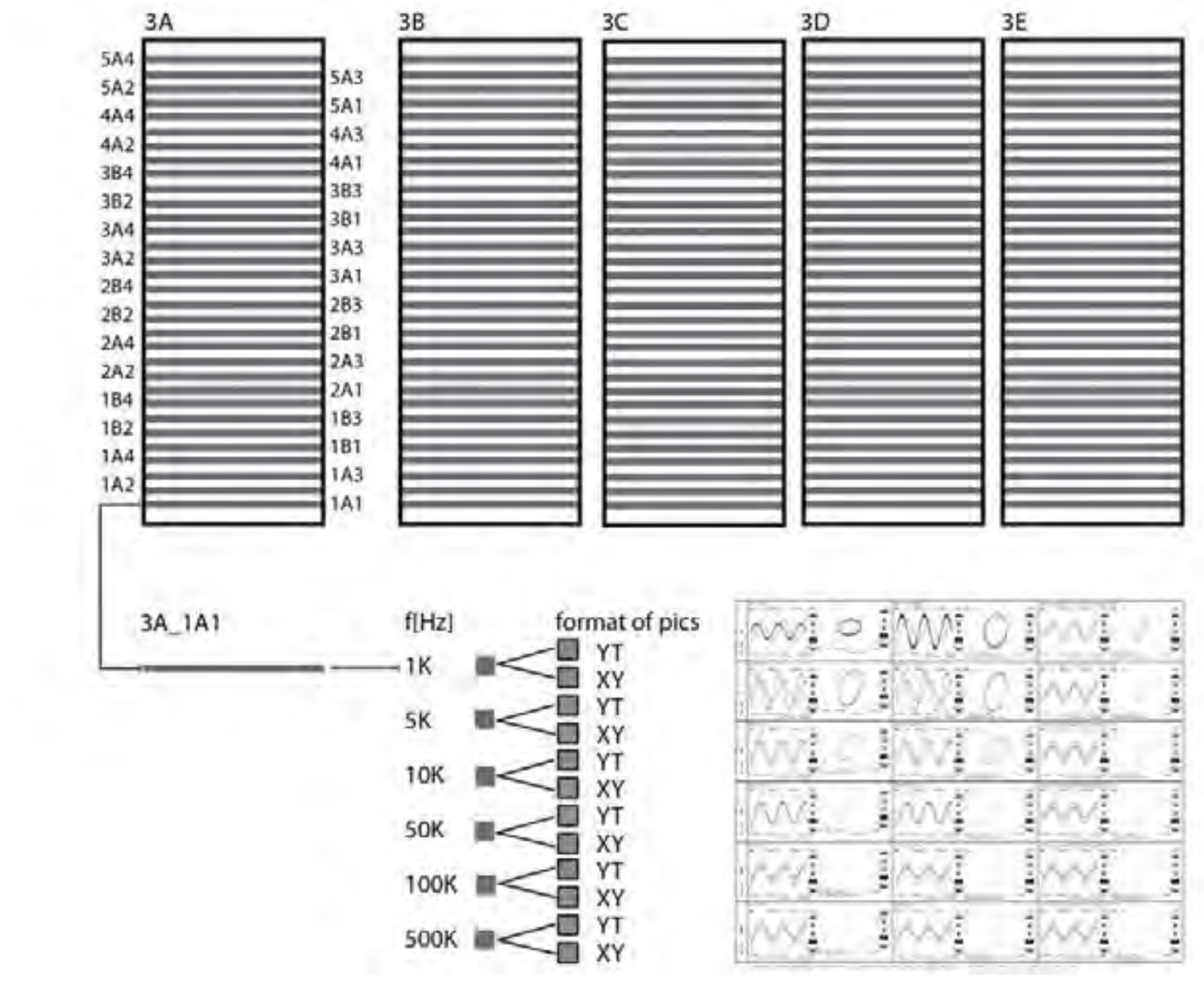


Fig 6. A diagram of the overall collected visual data of the study of amplitude and phase differences of a double knit structure with five different conductive yarns (3A-3E) that are investigated with a signal generator and oscilloscope.

Each condition was measured with a different input signal frequency, with the format of data collection towards evaluation shown in Figure 6. Thus, each condition and each strip was measured with 1kHz, 5kHz, 10kHz, 50kHz, 100kHz and 500kHz frequencies, as those are commonly achievable. Having 8 different patterns, each with 4 different input-knit distances, being measured at 6 different frequencies and 3 different conditions, with both standard and Lissajous-figure, gives 1152 measurements for each full knit sample. Our initial testing is limited to three of the five different electroconductive materials, as those have different material constructions: silver-coated fibres(3A), silver and nylon fibres(3B), and steel and cotton fibres(3E). Thus, there are a total of 3456 individual measurements. For the purposes of understanding the method, we focus mainly on the phenomena happening in lower end frequencies, although we touch upon the qualities of different electroconductive materials in the higher frequencies.

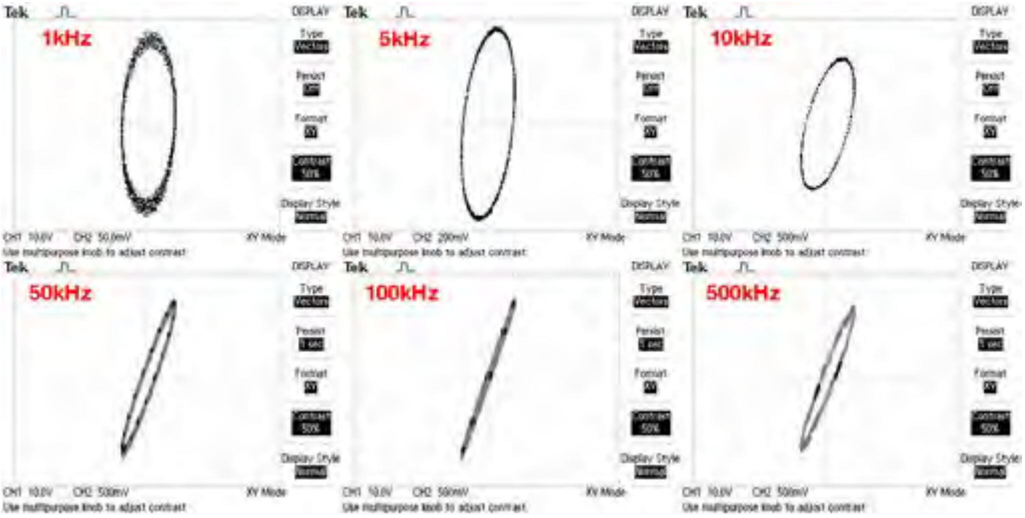


Fig 7. An example set of the Lissajous-figures that are typical to capacitive signalling signals

An example set of the Lissajous-figures which are typical to capacitive signaling signals are shown in Figure 7. The key things to look for in the figure are the Channel 1 (CH1) and Channel 2 (CH2) voltage scales, shown in the left-hand bottom of each screenshot. It shows how different the signal strengths are by describing the size of each unit of distance in the screen. For example, on the top right, one vertical "box" is 500mV, meaning that the signal in CH2 has 1,25V in amplitude. This is the voltage that is generated by the 10V input amplitude, which is visible in the CH1, or horizontal axis. In practice, the voltage in CH2 is the useful voltage for signal analysis, to evaluate the signal that has "jumped" through the knitted capacitive structure from the input-knit. Another thing to note is the diminishing surface area and the tilting of the pattern, indicating how much the output signal is timewise behind or ahead of the input signal, called lagging or leading, respectively. This behaviour is evident in the materials, and the output signal lags in the lower frequencies, as shown by the top row, and changes from lagging to leading with higher frequencies, as shown by the bottom row. Whether it is lagging or leading can be seen when adjusting the frequency and observing the behaviour of the Lissajous. If there is only a straight line, i.e. surface area is minimal, then the input and the output are both in the same phase, there is no leading or lagging. This is a good characteristic to look for in a signal transmission line, as the distortion is minimal.

Note that the CH2 setting changes, and thus the vertical size is actually increasing throughout the frequencies, while CH1 is fixed at 10V. Also, in 50kHz and above, the Lissajous appears dotted, however the digital persistence is turned on to create a visually closed loop.

Measuring the knit differences

In order to see how the material and knit patterns change the output, we measured all patterns in three samples and then started to pore through the differences. Our primary concern was to see if the aesthetics would influence the signal, and if so, how would it be visually perceivable. Thus, we start with the distance of the input-knit, and then continue to the effects of the pattern (both input strip and the measurement strip). Finally, we look at how different electroconductive materials affect the signal.

Evaluating the input-knit distance

In Figure 8, the differences caused by the distance of the input-knit at 1k and 5k are shown, using 3A material and sample knits 1B1-1B4 and the OPEN condition.

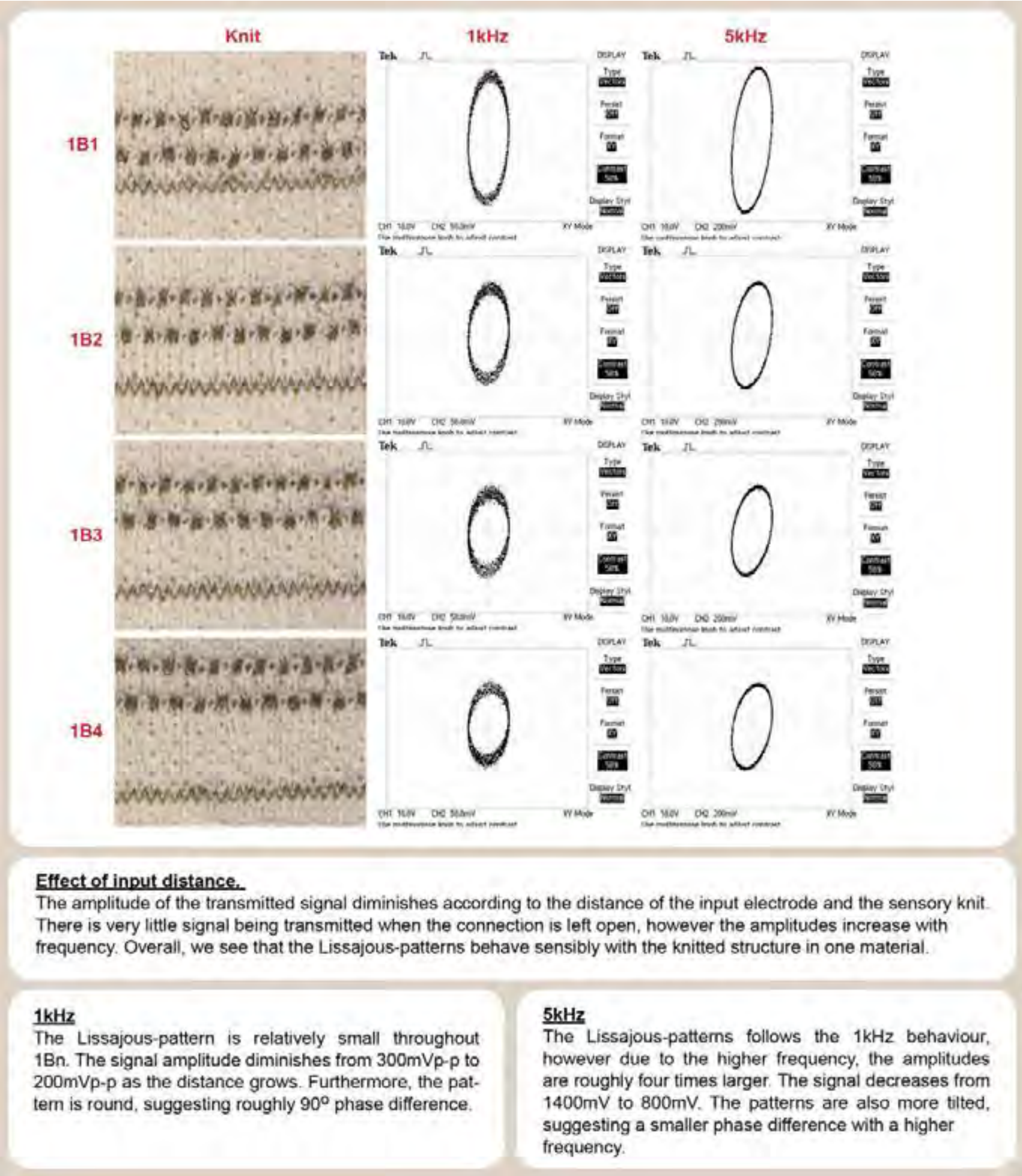


Fig 8. The line distances and the effects with 1kHz and 5kHz with material 3A.

Evaluating the differences of the input-knits

For the next evaluation, the different input-knits are compared with a fixed sensory knit structure, with two different sensory knits with the OPEN condition in material 3B, as seen in Figure 9.

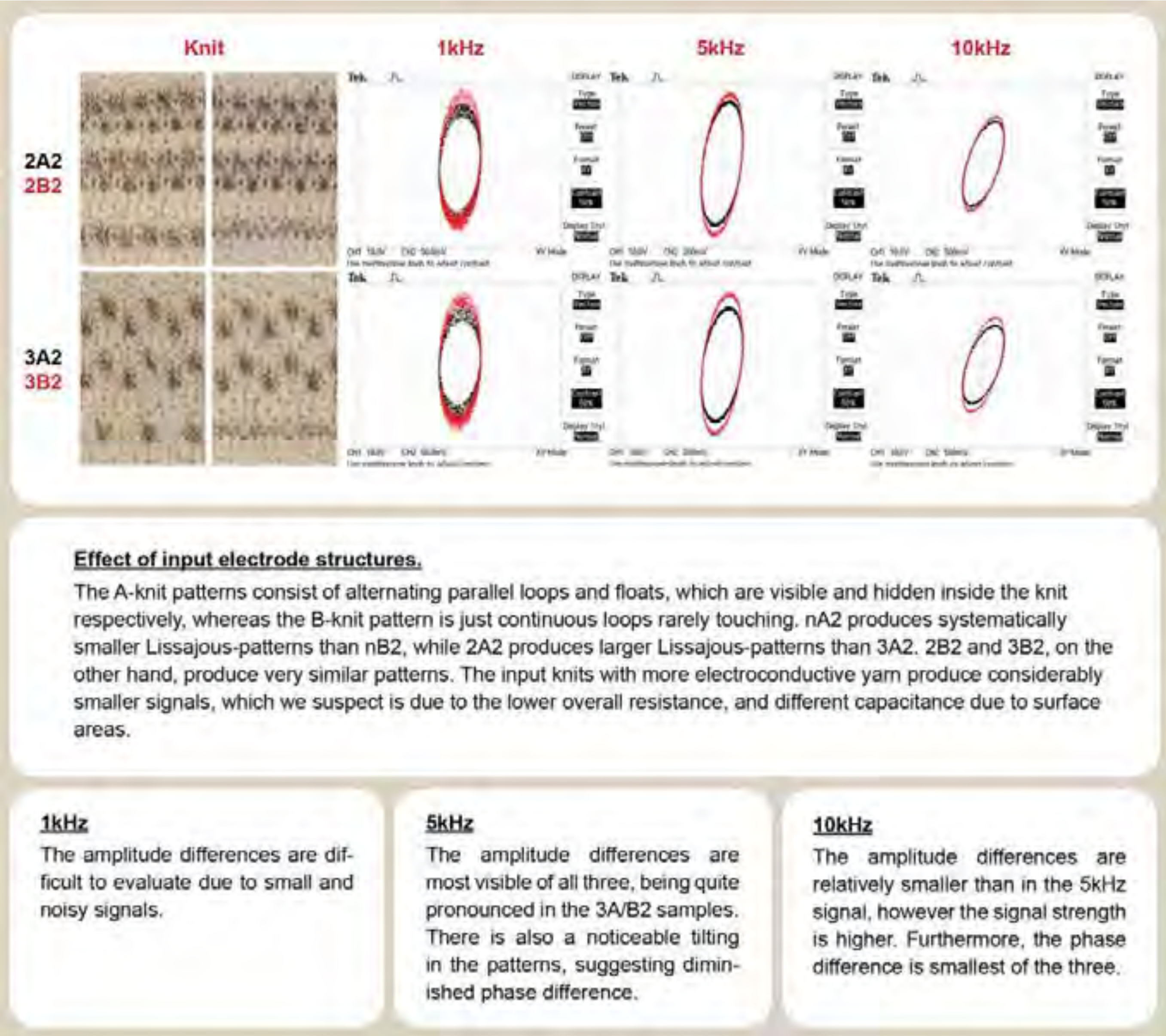


Fig 9. Effect of the input-knits, nAn knits on the left, and nBn knits on the right.

Evaluating the size of the sensory knit

The next measurements focus on the size of the sensory knit structure, which are shown with three different materials, 3A, 3B and 3E in Figure 10, with OPEN condition with10kHz frequency. The patterns were selected to have the same distance between the input-knit and the edge of the sensory knit. The amount of electroconductive yarn increases progressively through patterns 1, 2 and 4/5. However, patterns 4A1 and 5A1 have very similar amount of yarn, with the only difference in visual appearance, a chequered pattern or a straight pattern.

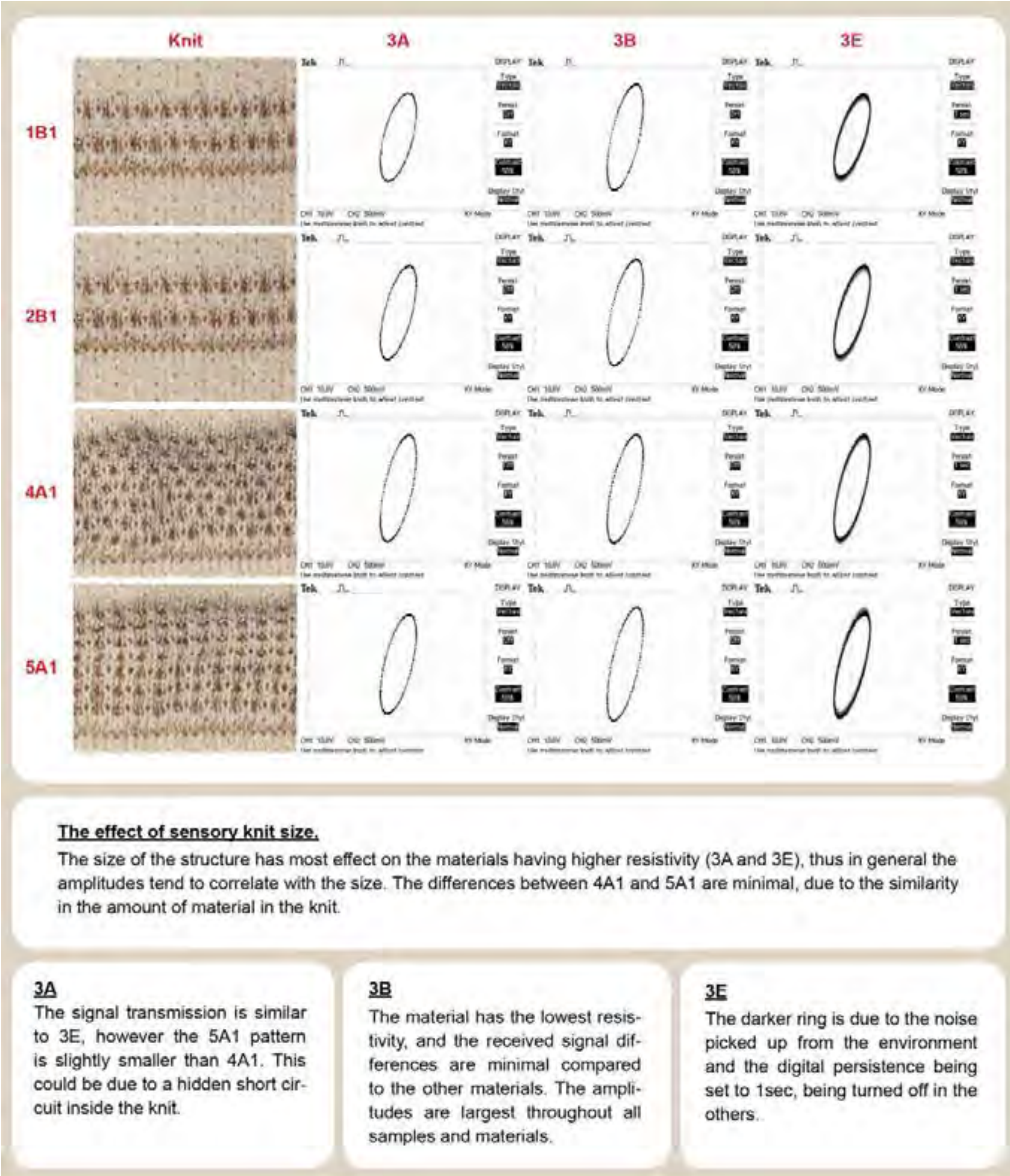
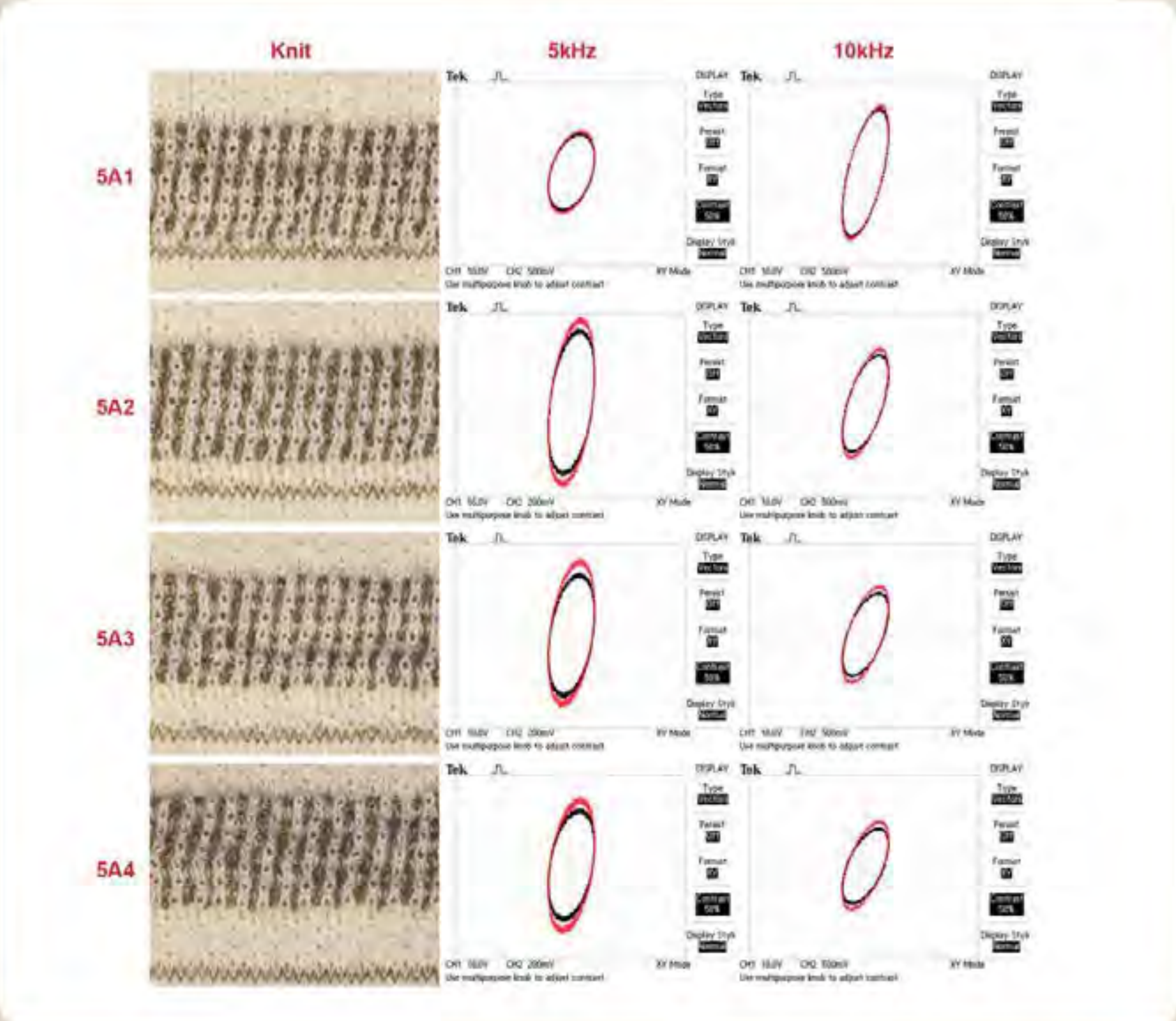


Fig 10. Effect of sensory knit size, 10kHz.

Evaluating the INSULATED and OPEN conditions

The comparison between the INSULATED and OPEN conditions in material 3A, with patterns 5An at frequencies of 5kHz and 10kHz are shown in Figure 11.



Effect of knit conditions.

The comparisons between the INSULATED (red) and OPEN (black) conditions are shown superimposed, with the difference clearly visible in the patterns, with the exception of 5A1. In 5A1, the signal appears already more capacitively coupled due to the close proximity of the input electrode and the sensory structure, than the others. The increased coupling through the insulated conductor has smaller effect on the signal at the higher frequency. Otherwise the patterns follow the behaviour similar to the increase of the input line distance (Figure 8.).

5kHz

The voltage difference between INSULATED and OPEN is roughly 200mV throughout all of the knits.

10kHz

The voltage difference between INSULATED and OPEN is roughly 300mV throughout the knits. With 5A1, the difference is only 150mV.

Fig 11. Material 3A, with 5An knits OPEN (black) and INSULATED (red).

Evaluating the material differences

The materials can behave differently due to their different resistivities, and the yarn structure. The differences between 3A and 3E are superimposed using two frequencies and OPEN and CLOSED conditions. The pattern used for the measurements was 2A3.

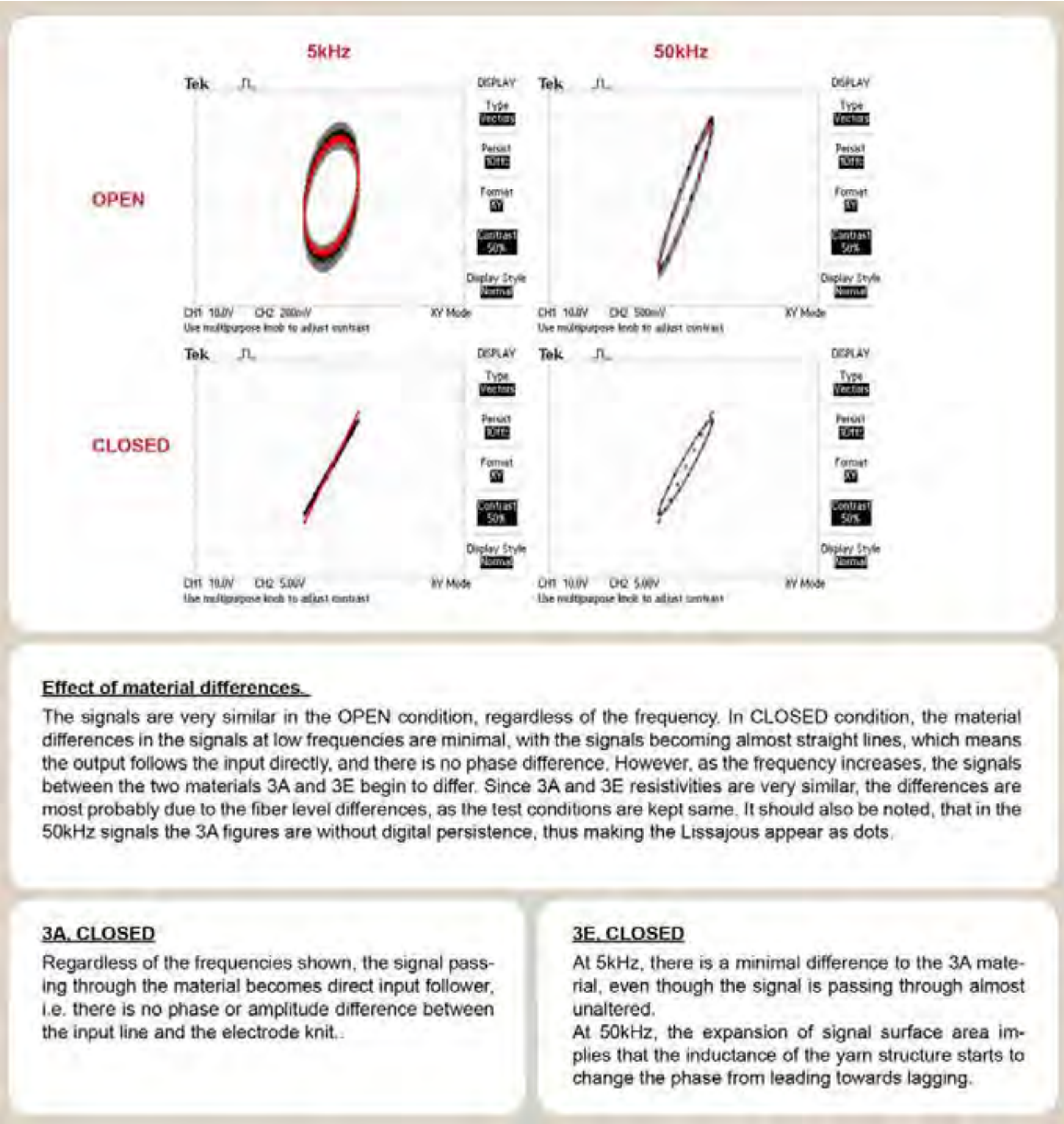


Fig 12. Differences of a 3A (red) and 3E (black) materials in 2A3 -pattern.

Emergent Semiconductive Properties

While the majority of the knit-patterns created with 3E follow the leading-to-lagging behaviour with the increase in frequency, we observed a phenomenon present only in some of the 3E knit patterns, which is not explained by the normal passive components (inductance, capacitance and resistance). Thus, the Lissajous-patterns did not initially seem to make any sense. The patterns are shown in Figure 13, and are only clearly visible in the CLOSED-condition, lower frequencies. However, 3E material is known to oxidise, forming a surface layer behaving as a semiconductor. There are several papers, summarized by Yin, D'Haese and Nysten (2015), which describe the properties of the semiconductive layer formed to the surface of the steel yarns. In their paper, a p-type semiconductive layer is described as being oxidised specifically on the surface of the Bekinox-yarn, the same yarn as ours.

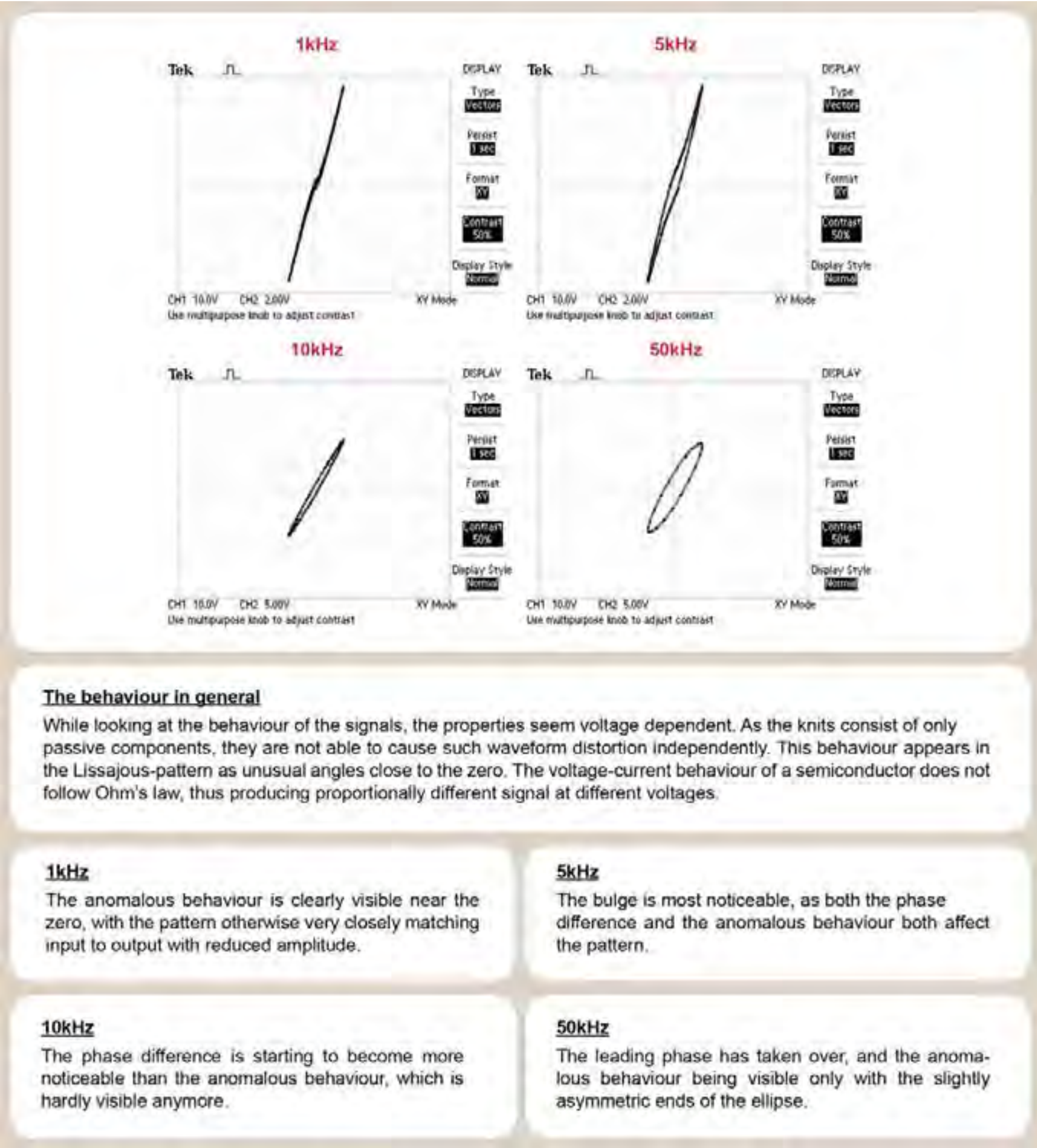
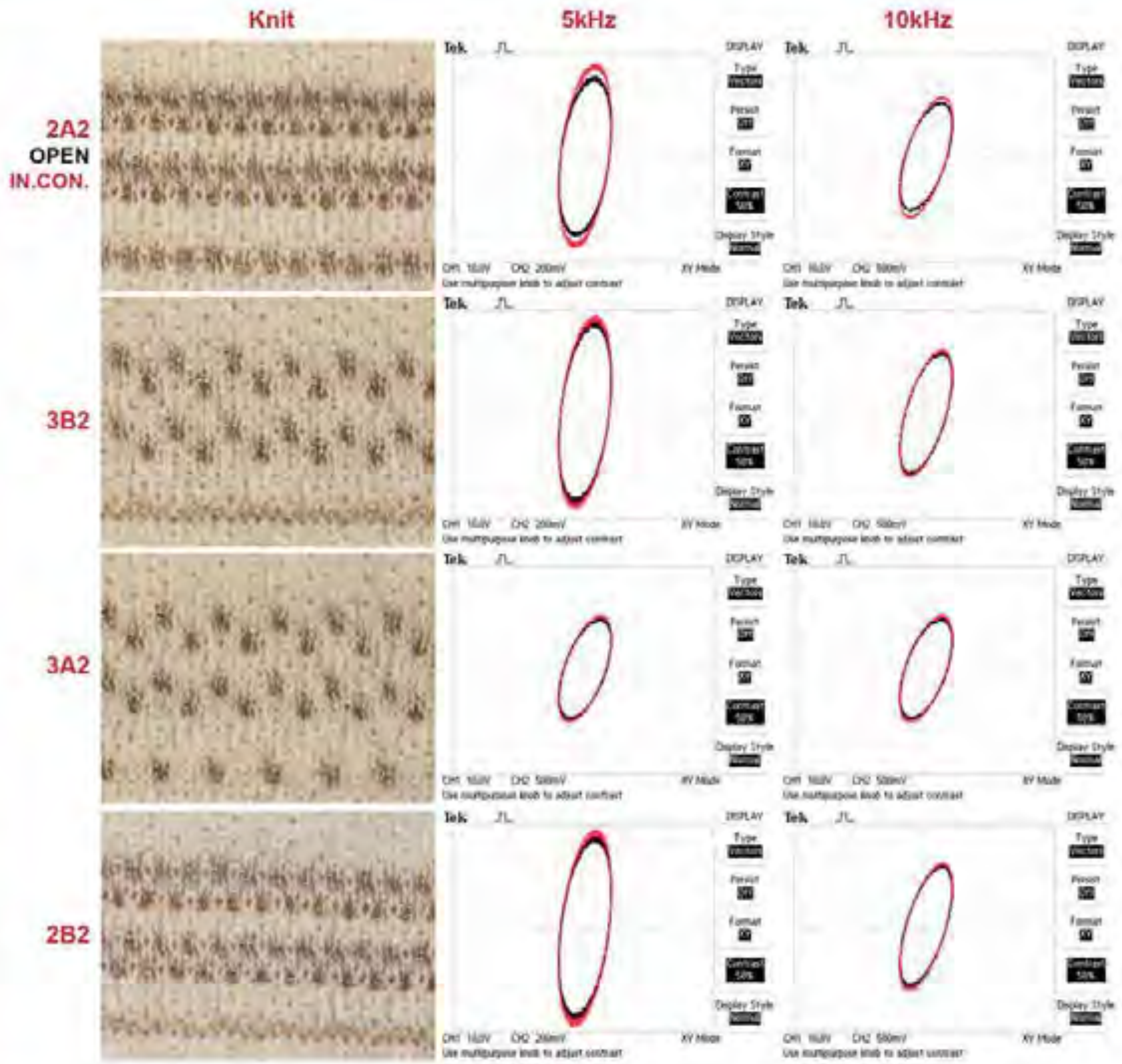


Fig 13. Semiconductive surface layer effects on the 3E 1B4 sample

Evaluating the sensory knit conditions

Finally, the effects of the knit pattern differences are evaluated using 3B material, between the OPEN and CLOSED condition, with the knit, 5kHz and 10kHz patterns shown in Figure 14. As the knit-patterns were selected to have an identical distance between the input-knit and the sensory knit structure, using the second distance beyond the close coupling as shown before, the effects of the two conditions can be evaluated.



Results of sensory knit conditions

The INSULATED condition systematically produces larger patterns than the OPEN. All of the samples have different amplitudes in the Lissajous-patterns, due to the INSULATED condition.
However in 2A2, the difference is much greater than in 2B2, which are otherwise identical except due to the structure of the input electrode. Similarly, the difference with 3B2 and 3A2 show the latter being slightly larger, when comparing the difference caused by the condition to the difference caused by the structure, although it is very small.

2A2

The difference between two conditions is most clearly visible in this sample, regardless of the frequency.

3B2

This pattern has the largest signals in both conditions. While the knit pattern is different from 2B2, they are signal-wise very similar.

3A2

The signals are clearly smallest in both frequencies. While very similar to 3B2 in knit-patterns, signal-wise they are very different.

2B2

The knit-patterns are similar to 2A2, however the difference of the input-knit suggests this pattern is less influenced.

Fig 14. The differences in knit patterns regarding OPEN (black) or INSULATED (red) conditions.

Discussion

The Influence of Textile Design Elements and Use Conditions

The pattern of the knit has a clear effect on the signal, and the Lissajous-figures follow the differences of the knit structures and materials. The effects of the distance between the input-knit(A) and the measurement line(B) can be seen in all samples; the bigger the distance, the smaller the pattern. This indicates that when the input-knit is located close to the sensory knit, the signal 'jumps' more easily to the sensory knit pattern, thus allowing the signal to transmit through the knit pattern. When comparing the distance effects in the OPEN condition with the INSULATED condition, the signal is influenced more in larger distances. Thus, the close proximity implies that the signal is protected. In terms of use context, this means that the signal is less influenced by the surrounding objects. One example could be to evaluate and design for the effect of insulation between the skin and the conductive lines, to create a reliable signal pathway. Alternatively, it could be used to design a sensory area, where the distances are selected to maximize the effect caused by the external conductive objects, such as when touching.

In addition to the distance, the input-knit has a considerable effect on the signal. The continuous line electrode knit patterns tend to produce the largest Lissajous-patterns. When the input-knit becomes visually more "loosely pixelated", in other words, when there are more hidden floats, the Lissajous-pattern size changes accordingly, i.e. becoming smaller in low frequencies. When comparing the influence of the input-knit in different conditions, the "loosely pixelated" tend to have a larger difference between OPEN and INSULATED. Even if the signal in OPEN would be originally smaller, the size change is relatively larger. This could be useful for the development of electrodes where the signal changes according to pattern. Such could be, e.g. a slider, where the absolute position can be tied to the visual density of the pattern.

The Lissajous-patterns correlates with the sensory knit pattern size, in materials with lower electroconductivity. In material with high electroconductivity, the Lissajous-pattern size did not correlate similarly, however the Lissajous-patterns were consistently larger than with the less conductive materials. Thus, the knit size becomes less relevant with materials having good electroconductivity. In OPEN and INSULATED, the Lissajous-pattern sizes directly follow the resistivities of the electroconductive materials, with 3A, 3E and 3B, from highest to lowest, respectively. It should also be noted, that 3A and 3E are very close to each other, while 3B resistivity is roughly two decades smaller. The fibre structure differences become obvious in the higher frequencies, especially with the CLOSED condition. While 3A and 3B behave identically, regardless of the frequency, in 3E the Lissajous-pattern is frequency-dependent. In lower frequencies, 3E pattern is a straight line Lissajous-pattern, with the output being the same as the input. This changes in higher frequencies, where the pattern becomes round. In the same condition, 3A and 3B are always straight, directly connecting input and output. Additionally, some of the 3E knits exhibit signs of semiconductive properties in the Lissajous-patterns.

The selection of the materials can be used for different purposes, with good conductors acting as better signal paths, and using more fibrous materials and active materials for sensor applications. Thus combining different materials to produce sensorial knits at a distance can be explored with a wider variety of materials, as the effects of each can be identified separately. It might even be possible to use the semiconductive yarns as a specific sensor, as semiconductors are commonly known to be reactive to physical parameters, depending on the semiconductor.

Using Lissajous in textile design

While the Lissajous-pattern method provides means for establishing a pattern of behaviour for different factors influencing the signal, likewise the method also can reveal electrical similarities that can offer a possibility for exploiting sensorial and aesthetic expressions of the knit pattern. The following two examples of such are identified and discussed as follows:

An example of a similarity with regards to the input electrode knit structure is evident in samples 3A1 and 3B2 that have been knitted with 3A material. When comparing the Lissajous-patterns of two different input-knits with different line distances at 10 kHz, the Lissajous-patterns reveal that the signal functions almost identically regardless of the three conditions. At the same time, the knits provide a different visual appearance to the pattern, as shown in Figure 15. Hence, if the visual expression of the design requires a less distinct outline to the pattern, this can be achieved without compromising the technical requirements.

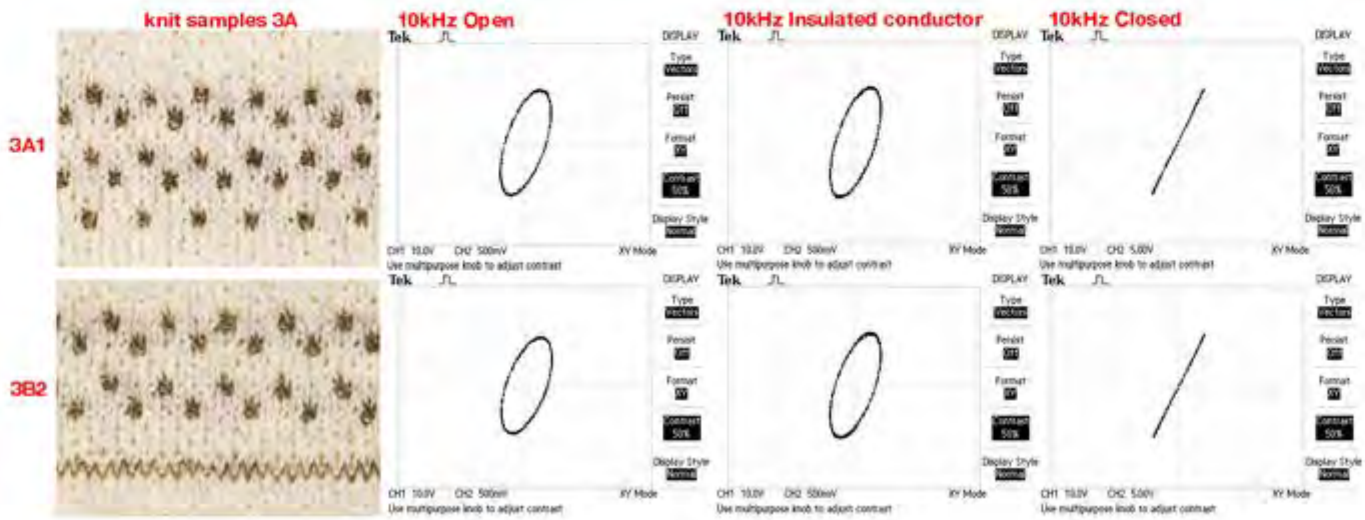


Fig 15. Using Lissajous to verify electrical similarity

A second example of a similarity concerns the knit patterns with material 3B, specifically 1A1 and 3A1, shown in Figure 16. As with the previous example, all three conditions exhibit almost identical behaviours at 10kHz, while the visual pattern is completely different. In this case, the input-knit distance is the same, however both the input-knit pattern and the sensory knit pattern are different. Pattern 1A1 is visually tight, almost indicative of a sensory boundary, in contrast to 3A1 which is more akin to a surface.

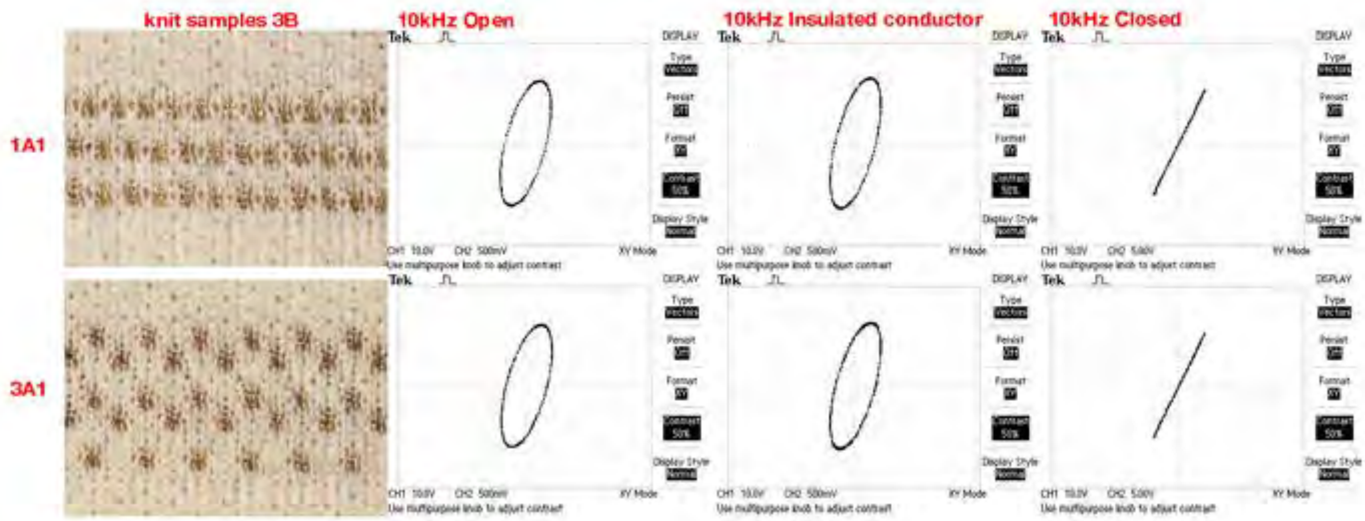


Fig 16. Using Lissajous to develop distinctly different visual appearances

In addition to the visual aspects, this approach could also be used from an economic perspective. As the method allows identifying patterns with similar electrical behaviour across different electroconductive yarns, it might be useful for selecting a more cost-effective yarn, or comparing the amount of yarns in different patterns against the cost and performance.

Practical Issues Concerning the Lissajous-method

While the actual method proved to be functional, two practical issues concerning the method, which consequently can influence data evaluation, need underscoring. Firstly, we discovered a challenge concerning the visual images of the Lissajous-patterns with different frequencies. As we started the measurements from the lowest frequency and consecutively increased the frequency, the Lissajous-patterns would increase in size. Thus, the figure would grow out of the oscilloscope display after the frequency was increased.

To ensure capturing the entire figure that would allow detailed, but also comparable, visual data, the voltage scale was altered *between the measurements*. Retrospectively, the measurements should start by identifying the largest Lissajous-pattern, and then progressively decrease the frequency. However, depending on the extent of the frequency scale being investigated, the Lissajous-pattern can become too small for visual inspection. In this case, the voltage scaling should be set again, and amplitude differences along with the scaling need to be considered to ensure a good comparison of the visual data throughout the spectrum. While we acknowledge this is obvious for the engineers, an example may be needed.

In order to clarify this issue, Figure 17 illustrates the visual differences of the same made up signals in three frequencies, 1 kHz, 5 kHz and 10 kHz displayed with a red box equivalent to the oscilloscope screen size, in two voltage scales, 50mV and 500mV. The illustration demonstrates the visual change of the same signals, based on voltage scale settings without adjusting for the signal's optimal appearance on the oscilloscope display.

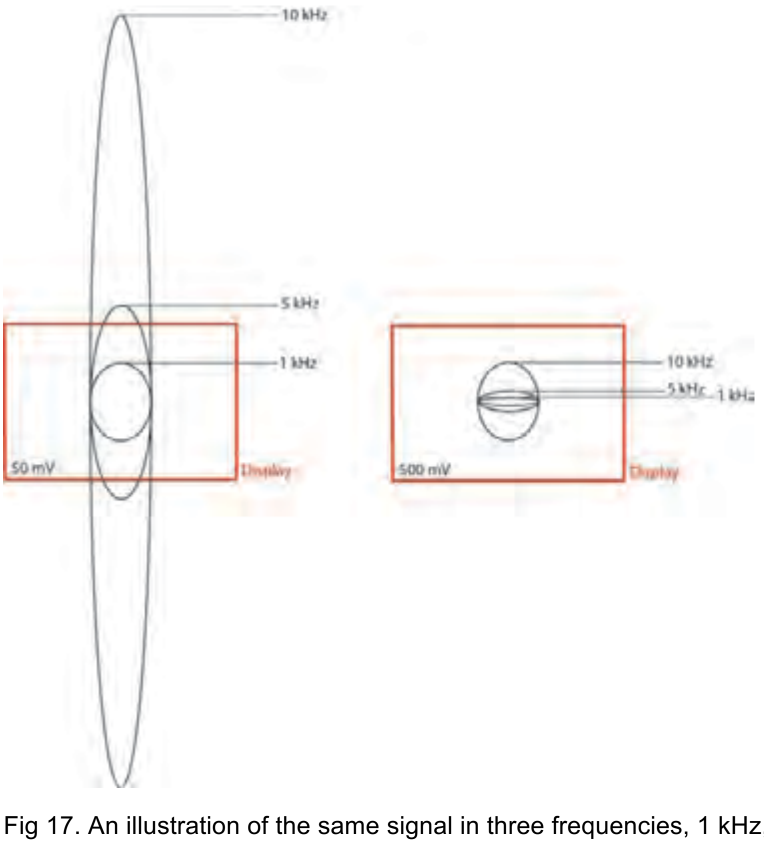


Fig 17. An illustration of the same signal in three frequencies, 1 kHz, 5 kHz and 10 kHz, in two voltage scales, 50mV (left) and 500mV (right).

Secondly, interpreting the visual differences of the Lissajous figures was also initially challenging. Whereas an electrical engineer found some visual changes to be significant, a textile designer considered visual changes as minute, as the visual differences were a matter of millimetres on the screen. However the skill for understanding the true differences and how they relate to design aspects became clearer as the experience increased.

Conclusion

The visual method presented here allows the textile designer to focus on the experiential qualities and textile design, without the need for complex mathematical modelling. We have adapted a well-known engineering method for the design use, and provided examples of how technical aspects, such as for signalling and sensing, can be evaluated with sensorial and aesthetic qualities in mind. The properties of the electroconductive structures were identified independently, to verify that each difference could be seen in the figures. Differences caused by distance of input-knit and the sensory knit structure, the different knit structures, as well as those by the different electroconductive materials (down to the fibre level) were identified. Accordingly, smart textiles can be developed with increasing independence, and the method provides a tool for designers and engineers to discuss, and to better understand different design decisions.

Acknowledgements

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Riikka Townsend

With an educational background in textile art, - craft and - design, and work experience as a freelance designer, Riikka Townsend has great diversity and thorough understanding of different aspects of textile design. She continues to deepen her theoretical and design practice knowledge in textile design as a doctoral candidate at the Department of Design in Aalto University School of Art, Design and Architecture, Finland. Her research interests are in developing new knowledge on smart textiles by exploring a design approach in addressing and assessing smart textiles as 'a sensorial material' through explorative material enquiry and prototyping.

Jussi Mikkonen

Having worked and taught at both university of technology, as well as university of arts and design, he has developed a positive perspective towards multidisciplinary prototyping. His doctoral work focused on prototyping interactions, drawing from both design research and electrical engineering. His research interests are on smart clothing and smart textiles, physical computing, interaction design, as well as art nouveau created with modern day technology.

Smart thermoregulating garments

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Abstract

For a human body to function properly the body core temperature needs to lie within a narrow range of about 37 °C. This temperature is, among others, sustained with adjusting the blood flow to the skin, as well as by sweating or shivering. In extreme hot conditions and, in particular when wearing protective clothing, heat gain exceeds heat loss and the body temperature increases. Specifically, every 1°C rise in body core temperature is accompanied by 1% reduction in gross efficiency and may eventually lead to reduced operational performance. Whereas, in cold conditions, peripheral vasoconstriction leads to cold extremities resulting in reduced coordination skills and higher risks for accidents.

In this project we aim at developing new, smart and innovative solutions for clothing which can actively influence body temperature. We thus aim at developing clothing that will provide intensity of cooling that will be reflecting the thermoregulatory state of the weather. Such clothing will improve thermal comfort in hot and cold conditions. Furthermore, it will serve to professional users, such as firefighters, who are exposed to extreme conditions for longer periods of time, to athletes helping them by improving exercise performance in hot conditions and for patients such as those with multiple sclerosis who are thermo-sensitive and where decreasing body temperature is shown to improve neurological symptoms.

We will reach this aim by combining different heating and cooling technologies with sensors and actuators where these will be integrated into new smart clothing prototypes.

Keywords
smart clothing, personal cooling and heating systems, thermal comfort, thermoregulation

Context of smart clothing project

The research field of smart clothing represents an interplay among fashion designers, industrial designers, engineers and physiologists. Thus, specialists who in general do not collaborate. However, in this project we established a platform in which these specialists meet, discuss and design together. In such manner innovative solutions regarding the thermal control of the human body are being found.

Clothing is used since early mankind to protect and isolate our body and, to impress others. However, in more recent developments clothing has been engineered for sports applications such as aerodynamic speed-skating suit and fast swim-suit. Furthermore, the overlap between human physiology and engineering is illustrated by the rapidly growing amount of clothing for health monitoring. Moreover, the overlap between fashion and technology is illustrated by the famous *twitter dress* [1] or the *3D printed corset* [2].

In our society problems related to the significant heat gain or heat loss conditions occur in many situations. For instance, in hot conditions where the body needs sealed protection (ebola suits and steel workers), cold conditions in which fingers and toes may suffer due to low temperatures, sports, medical (multiple sclerosis and rheumatic patients) and in workers exposed to rapidly changing thermal conditions (fork lift drivers).

There are various personal cooling systems currently available, where cooling is provided using phase-change materials, circulating water or vents. However, the intensity of cooling in such systems is not adapted to the thermoregulatory state of the wearer. Specifically, the intensity of cooling is not adapting to the body temperature and thermal perception of the wearer. This aspect is addressed in the concepts presented below. The concepts were tested on human participants in form of pilot studies.

Concept 1: Cooling vest for women with hot flashes [3]

Motivation: Women in the menopause frequently suffer from hot flashes. These occur typically10 - 20 times per day and last for about one minute.

Idea: Using thermocouples to monitor the skin temperature. Thus, through monitoring the local increase in skin temperature an upcoming hot flash will be detected. Immediately after the temperature increase, Peltier elements embedded into the vest provide cooling.

Embodiment: As indicated in Figures 1 a, b a circuit made out of Peltier elements, combined with thermocouples and flora Arduino board was formed. The Peltier elements are switched on alternatingly in order to provide appropriate cooling and thereby provide improvements in the thermal comfort.

Findings: Three women were asked to wear the vest (Figure 2) for about 60 min. From personal communications it can be concluded that women appreciated that the vest was elegant and light. Some of the women indicated that by wearing the vest they felt more comfortable as they were less afraid for the occurrence of hot flashes. Based on this reports it can be concluded that wearing the vest improves the comfort of the woman suffering for hot flashes.

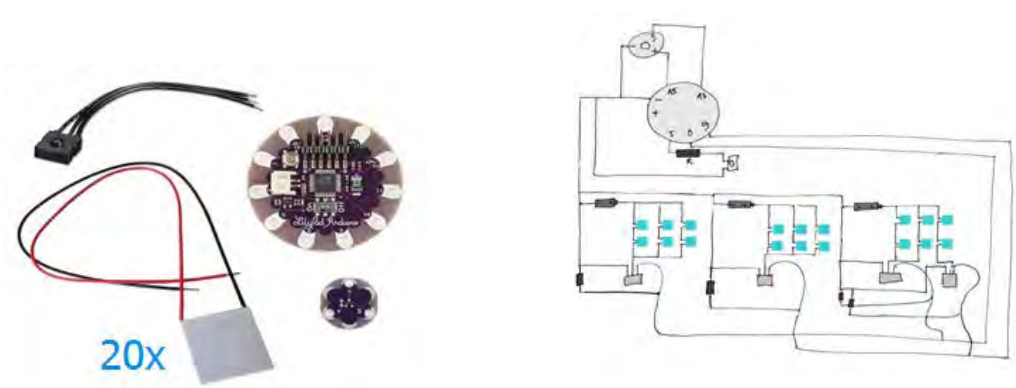

Figure 1 Peltier elements, thermocouples and flora Arduino board used for forming used to firm a circuit (a); sketch of a circuit (b).

Figure 2 Cooling vest used in women with hot flashes.

Concept 2: Cooling shirt for cyclists [4]

Motivation: On some instances cyclists can have difficulties with heat dissipation. In particular this is true for cycling up hill. However, during cycling downhill cyclists get commonly cold. It is suggested that these athletes would benefit from a clothing system that would provide cooling when they are cycling up hill and warming when cycling downhill.

Idea: Peltier elements can heat as well as cool and thus, are able to provide cooling or heating depending on the situation. This principle can be used in the cyclists who are cycling up or down hill. Since Peltier elements can cool only for short periods of time (few minutes) the cooling capacity needs to be increased for instance with using heat spreader foils and external cooling fins (Figure 3a).

Embodiment: 22 Peltier elements with attached external cooling fins were integrated in a cycling shirt. Most of the elements were put on the back side of a human body as such configuration allows more air for ventilation of Peltier elements.

Findings: The cooling shirt was tested on five young men while cycling outdoor (Figure 3b). Where the thermal perception of cold and comfort of wear was investigated. The participants reported that the perception of cold is pleasant. Furthermore, they indicated that their first impression was that the cooling shirt is heavy however, while wearing it they experienced it as light weight with no restrictions in movement.

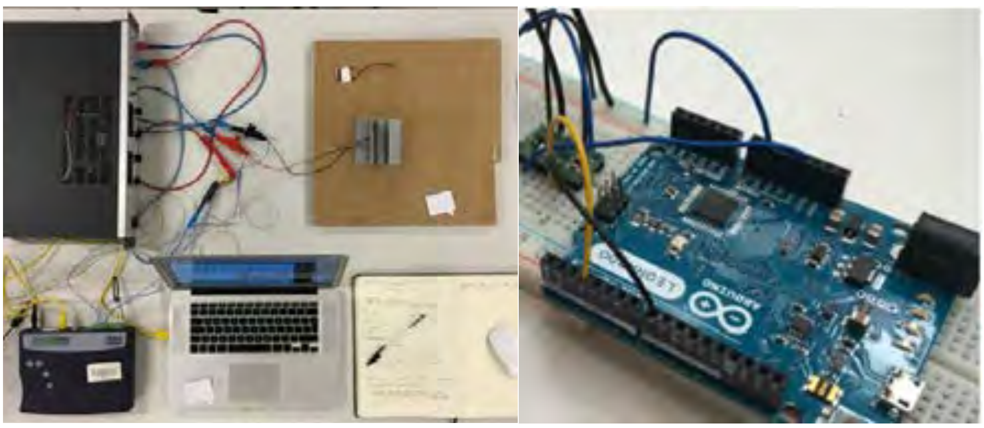

Figure 3: Test setup and electronics (a); embodiment and final result of cycling shirt being tested on participants (b).

Concept 3: External cooling system for rowers [5]

Motivation: During rowing large amount of heat is generated by large muscles groups of legs, upper body and arms. It is suggested that the performance of rowers is improved with providing cooling to the mentioned body regions.

Idea: If our veins cannot dissipate heat sufficiently we may as well design an external vein system for improving the transportation of the heat away from the skin surface. This can be achieved by using an open foam cooling pads and flexible tubes connecting the cooling pads where the water is used as medium for heat transport. Thus, the main principle of cooling is conduction of heat produced in the muscle toward externally positioned cooling pads.

Embodiment: Four cooling pads (Figure 4a) positioned at the front and four at the back were integrated into a rowing shirt. For connecting the tubes we used a custom made 3D printed connectors. In the present configuration the water was pumped from an external cooling bath.

Findings: By using an ultrasonic sealing we could impermeably seal the cooling pads. Infrared images (Figure 4b) showed that the cooling pads filled up completely after 3-5 minutes. In a follow up study the cooling capacity of the cooling shirt (Figure 4c) will be measured and modelled.

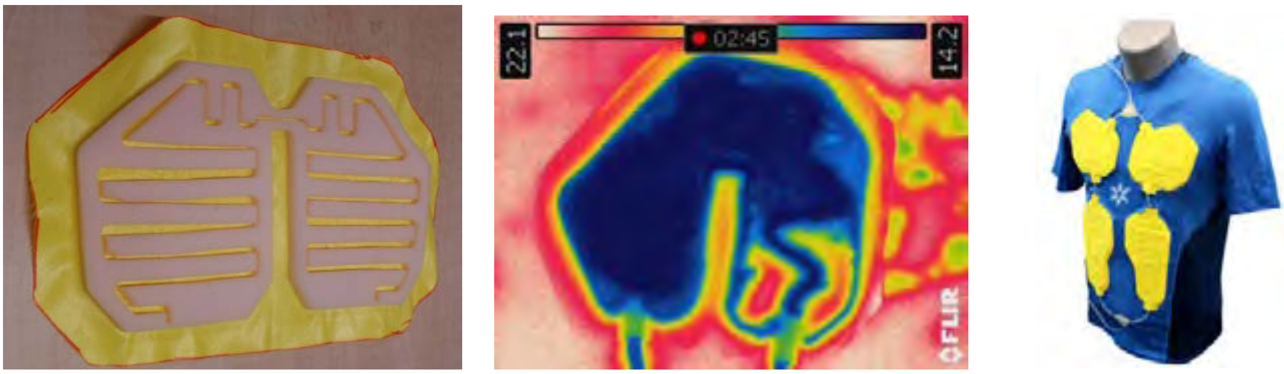

Figure 4 Open foam cooling pad (a); thermal image of the filled cooling pad (b); and final design of rower shirt (c).

Discussion

The focus of the present project is to develop innovative, smart garments that would adapt to the thermal status of the wearer. Currently, three working concepts have been developed, where however some difficulties were encountered. Specifically, when using Peltier elements we observed a disadvantageous side effect of heat production and its poor dissipation. Thus, the future work should focus on investigating possibilities of how this excess of heat can be removed. One of such possibilities would be combining the Peltier elements with ventilators. Thereby, using forced air flow to dissipate the excesses of heat. Nevertheless, the advantage of Peltier elements is that they are light weight, thus in opposite with phase change materials they do not impose significant weight onto the wearer [6]. Furthermore, in case of using water as a medium to providing cooling it is suggested that the surface of cooling should be expanded which could be achieved with using cooling patches based on foam and integrated into the clothing. As it can be seen, our work in the future will be focused not only on developing new concepts, but also optimizing the concepts that have been already developed.

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Authors

Prof. Kaspar M.B. Jansen received his MSc degree in Chemical Engineering from Twente University, The Netherlands, in 1987 and the Ph.D degree from Delft University of Technology, The Netherlands in 1993. He worked as an associate professor at the Mechanical Engineering department of TU Delft on residual stresses during micro chip encapsulation. Since April 2012 he moved to the Industrial Design Engineering faculty and is now chairing the Emerging Materials group. His current focus is on smart materials and textiles and designing with electroluminescence.

Dr. Nina Bogerd earned her PhD at Vrije Universiteit, Amsterdam. In her research work conducted at Department for Protection and Physiology, EMPA St. Gallen, Switzerland she focused on investigating the interaction between human body and personal cooling systems. Afterwards she was appointed as a lecturer to Department for Physiotherapy, Faculty of Health Sciences, University of Ljubljana and as a host lecturer of Environmental Physiology at Faculty of Mathematics, Natural Sciences and Information Technologies, University of Primorska, Koper. In 2015 she started to work as a postdoctoral research fellow at Amsterdam University of Applied Sciences. And in 2016 she moved to Technical University in Delft to work with Prof. Kaspar Jansen at the group of Emerging Materials.

program features

Presentation by Diana Scherer

New Material Fellow at Het Nieuwe Instituut

Interwoven - Exercises in rootsystem domestication

Diana Scherer works with wheat, and specifically its fast-growing root system. By growing the wheat on a subterranean template, she can manipulate the root system to create 'woven' patterns. Scherer takes inspiration for these patterns from the geometric structures of cells, snowflakes and shells. The form of the textile-like material she cultivates is dictated by the 3D-printed bioplastic template: sometimes finely tuned, sometimes fairly undirected. Seed, soil and water are the only ingredients necessary for the process. When the roots have grown into the desired pattern, Scherer harvests the crop. She cuts the wheat down and dries the root structure. The photographs she takes of the resulting textiles are an integral part of her working process, but she also preserves the actual materials.

For her research, Scherer works together with biologists and ecologists from the Radboud University in Nijmegen. The project is of interest to academics because of the important role that roots play in the storage of greenhouse gases and because of the project's potential to develop a material that combines its beneficial ecological characteristics with a new form of natural production. Together with botanist Gerard van der Weerden, Scherer is exploring the possibility of growing complete items of clothing underground.

In 2016 Diana Scherer was the winner of the New Material Fellow for Interwoven and received a fellowship at Het Nieuwe Instituut for further research. She presented her work in Milan in April this year and is invited by several partners form the international materials & design network to share her views on research and present her current work (e.g. in Spain, Germany)

The researcher as designer or the designer as researcher; stories from the studio

Short presentations from Het Nieuwe Instituut's guest designers working with Alive. Active. Adaptive materials. Participants:

Roos Meerman

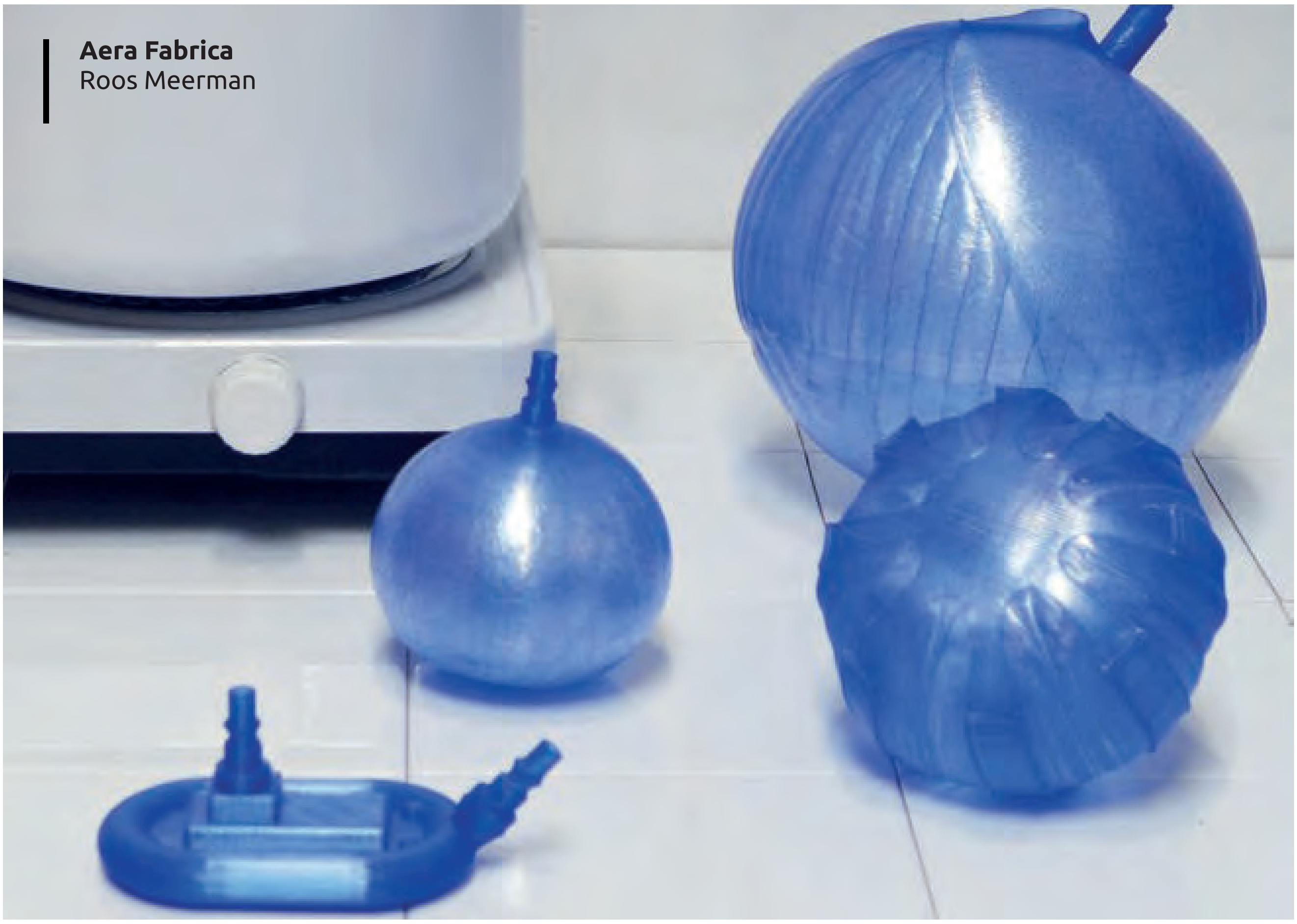
Roos Meerman is an Arnhem based designer, who researches natural phenomena, looking for specific characteristics and the limits of a material by playing with it. Her goal is to control materials, yet in such a way that it retains freedom of movement. Because of this approach, the final outcome of her projects is always unique. Her self-developed or hacked techniques and machines represent an analytical and fundamental designprocess and underline her scientific attitude towards design research. Roos Meerman's work has received several awards; in 2014 she was New Material Fellow at Het Nieuwe Instituut and more recently she won the Bio Art & Design Award 2016 with Lilian van Daal for their research project 'Dynamorphosis, in which the invisible biological processes of the body merge with 3D printing technique, to show the hidden beauty of biological processes.

www.roosmeerman.com

Xandra van der Eijk

Xandra van der Eijk graduated from the Interfaculty ArtScience at the Royal Conservatory in The Hague, after graduating from Graphic Design (BA) at the Royal Academy of Art, The Hague. In her work Van der Eijk investigates natural processes and elements, whilst the concept of time is a recurring theme. Through a combination of theoretical research and frequent experiments, she develops conceptual works with a strong visual component. In these works, she documents and describes, but never fails to allow space for poetry. In 2017 she developed the project 'As Above, so below –Design research', in collaboration with Kirstie van der Noort, in response to the theme of "Harvest". In the current state of consumer driven culture, there is an urgent need for alternative forms of mining. This realisation led to a material research into crowdmining stardust as a new source for rare earth metals from space. Van der Eijk received the Paul Schuitema-prize in 2008 and was nominated for the STRP Talent Pit Award, BLOOOM Award and Bio Art & Design Award.

www.xandravandereijk.nl



Aera Fabrica
Roos Meerman

Momentum
Xandra van der Eijk

Spark of life
Teresa van Dongen

Phygital virtuosity
Bastian de Nennie

Teresa van Dongen

Teresa van Dongen is an Amsterdam based designer, who has always been fascinated by nature and science. While studying biology, she discovered that there are many secrets of nature that remain almost unknown and that great developments in the field of science very often don't make it outside the doors of a laboratory. Next to her scientific education she had never given up on her creative hobbies like scenography (theater stage design), sketching and her interest for interior architecture. This combination of fascinations lead her to apply in 2010, after two years of exact studies, for the Design Academy Eindhoven. In her research she has, amongst other things, focused on light as a translation of energy, the transparency of glass and what it beholds and the physics of movement. Examples of what this research leads to are: 'Spark of Life', a "living lamp" (bacteria based) that only need a teaspoon of acetate every two weeks and some new water every month. And 'One Luminous Dot', a tribute to our one and only planet; a bioluminescent light installation, that refers to our galaxy in which the Earth is but one little dot. A star of glass tubes holds a fluid with a special bacteria obtained from the skin of an octopus. Movement keeps the bacteria oxygenated, causing blue waves to light up. A reminder to cherish the planet we live on. In June 2014 Teresa van Dongen graduated Cum Laude at the Design Academy Eindhoven and in 2015 she won the Dutch Design Award in the category of Young Designer.

www.teresavandongen.com

Bastiaan de Nennie

Bastiaan de Nennie is a graduate from the Design Academy Eindhoven, the Netherlands. He lives and works in Berlin. Bastiaan positions his practice: the intersection of the two ever more intertwining worlds of the physical and the digital. He departs from a pre-digital reality: the world of things we have, mostly, experienced through their forms, colours, fragrances and textures. Once selected, these objects are 3D-scanned, the scans are dissected, and the components are used as building blocks for new digital creations. After a multifaceted computer-based creative process, these then reappear as a new blend of 'phygital' presences materialized in the form of 3D-printed sculptures - a new creational process that is the basis for sculptures with before unknown shapes and colors. This continuous travelling, in and out of these two presences - the physical and the digital world - raises questions about the dominance of the material over the immaterial and our belief that the atomic structure is more real than its virtual counterpart, or that the physically made is more authentic than the digitally processed; or - in its barest form - the relationship between man and machine.

www.bastiaandenennie.com

Closing Panel discussion

Chaired by Elisa Giaccardi

Participants:

Anna Vallgårda - *(see bio p. 18)*

Maurizio Montalti - *(see bio p. 20)*

Tom Fisher

Professor Tom Fisher is Research Coordinator for the School of Art and Design, representing research on the School Executive Group. In this role he wrote and developed NTU's submission to REF Unit of Assessment D34, Art and Design, History, Theory and Practice, working across the college to include colleagues in the Sustainable Consumption and Product Design research groups. He has led research funded by the AHRC and Defra, participating in work funded by WRAP. He is a member of the AHRC Peer Review College and reviews research bids for AHRC, ESRC and EPSRC. He is a member of the Design Research Society Council and leads the Special Interest Group OPEN (Objects, Practices, Experiences, Networks). He applies his expertise in Art and Design research training to his teaching on the School's Masters courses, as well as the University's credit-bearing Professional Research Practice course. Professor Fisher's research is distinctive in its span of disciplines, building from his direct experience of craft practice through theory and methods from the human sciences - he has been published in Design History and Archaeology.

Roos Meerman - *(see bio p. 366)*

Ricardo O'Nascimento

Ricardo O'Nascimento is an artist and researcher on the field of new media and interactive art. He investigates body-environment relations focused on interface development for worn devices, interactive installations and hybrid environments. He is the founder of POPKALAB - a design/research studio focused on innovation on the field of wearable technology. He holds degree from PUC - SP , SENAC - SP and the University of Arts and Industrial Design Linz at the Interface

Culture Department. Currently he works in his studio and teaches at some places. He received awards including CYNETART award 2012 and Rumos Arte Cibernética. His works have been featured in several museums, galleries and art festivals like Ars Electronica, FILE, LABoral, V2, Instituto Itaú Cultural, Soft Galleri, Transmediale and MAC - Coruña, among others.

Bastiaan de Nennie - *(see bio p. 369)*

EKSIG2017 Venue

EKSIG2017 is hosted by **Het Nieuwe Instituut, Rotterdam.**

Het Nieuwe Instituut (Rotterdam) increases public appreciation of and the social significance of architecture, design and digital culture, and promotes exchange between these disciplines. Het Nieuwe Instituut researches, presents and represents architecture, design and digital culture through an extensive programme of exhibitions, lectures, debates, workshops, research projects and educational activities.

From its inception, Het Nieuwe Instituut has positioned itself as an organisation with an international scope. This is reflected in the institute's three long-term research tracks, its exhibitions programme, its many activities abroad and the contribution of numerous foreign researchers, designers, makers, critics and curators to its activities. Het Nieuwe Instituut closely collaborates with the International Materials & Design Network to organize projects with international partner organisations, to enable knowledge exchange on innovation in materials, design and sustainability and to support talented Dutch designers to expand their international networks.

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